COMBUSTION

11 1931

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WHIPPANY PLANT, JERSEY CENTRAL POWER & LIGHT COMPANY

Graphical Representation of Engineering Equations

By D. S. DAVIS

Typical Gaseous Fuels

By WM. L. DeBAUFRE

OTHER ARTICLES IN THIS ISSUE BY

E. R. WARRINGTON • C. H. S. TUPHOLME • DAVID BROWNLIE • O. O. ZAPPE • E. B. RICKETTS

October 8, 1931

Subject: T. B. Hospital
Power Plant

Combustion Engineering Corp.,
City.

Gentlemen:

We have made a careful inspection of the boiler installation and find that all conditions of the drawings, specifications and contract have been fully complied with. We wish to commend you upon the satisfactory manner in which you executed your work. Mr. Montgomery, the Mechanical Director of the Hospital, is well pleased with the installation.

Very truly yours,

Harry Hake,
Samuel Hannaford & Sons,
Associate Architects

•• THE MECHANICAL DIRECTOR IS WELL PLEASED ••

Three Walsh-Weidner Sectional Header Boilers fired by heavy duty Type E Stokers comprise the units recently installed by this organization in the Hamilton County Tuberculosis Hospital at Cheviot, Ohio. The letter from the architects, reproduced on this page, tells the rest of the story.

◆ ◆ ◆

The advantages and details of construction of both the Walsh-Weidner Boilers and Type E Stokers are set forth in literature which we shall be glad to send you upon request.

COMBUSTION ENGINEERING CORPORATION

200 MADISON AVENUE · · · NEW YORK, N. Y.

COMBUSTION

VOLUME THREE • NUMBER SIX

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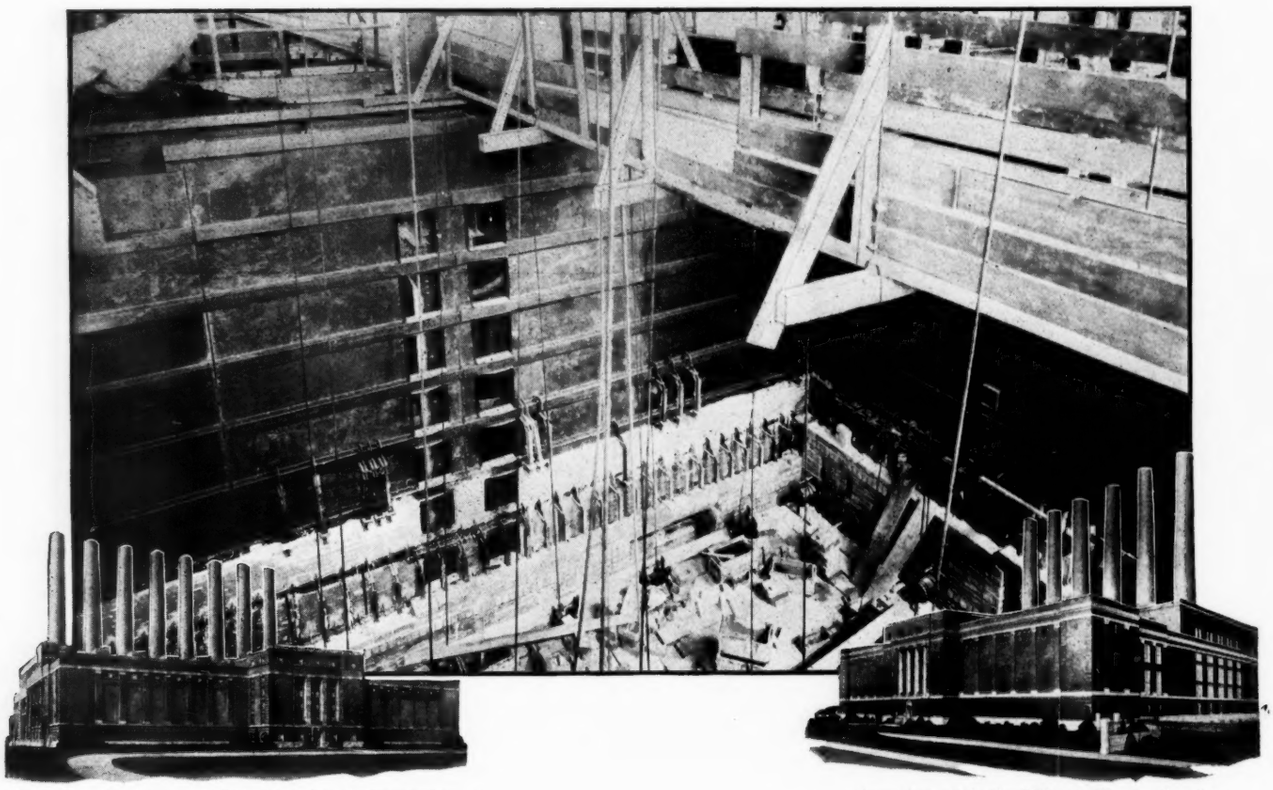
2 Modern Power Plants *insulate to save fuel . .*



Ashtabula plant, latest unit of Cleveland Electric Illuminating Company.

Avon plant of Cleveland Electric Illuminating Co.

Cleveland Electric Illuminating Company uses Armstrong's Insulating Brick in Avon and Ashtabula units

HEAT stays where it belongs in both the Avon and the new Ashtabula plants of the Cleveland Electric Illuminating Company. Armstrong's Insulating Brick in the settings of the steel-encased boilers prevent wasted B. t. u.'s.

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Both Armstrong's and Nonpareil Insulating Brick are light and strong. Light weight pays in many installations where strain on the surrounding materials must be avoided. Strength is necessary, too, for the high constructions frequently found in high temperature installations.

Choose the brick that best suits your needs. Either will show a definite saving in fuel. Instances are on record proving fuel savings of 10% to 40% a year—enough to pay the cost of insulation many times over.

Armstrong's and Nonpareil Insulating Brick are furnished in all standard fire brick sizes. Special shapes can be had on order. Armstrong engineers are at your service to tell you more about these Armstrong products and the savings they can effect in your plant. Samples of each will be sent on request. Armstrong Cork & Insulation Company, 934 Concord St., Lancaster, Pennsylvania.

Armstrong's (A) Product

Armstrong's Insulating Brick
Corkboard and Vibracork

COMBUSTION

VOLUME 3 DECEMBER 1931 NUMBER 6

Heat Transfer Fluids

R. C. ROE

THE first commercial power plant using organic heat transfer fluids has been placed in operation. This plant, the Bremo Station of the Virginia Public Service Corporation, uses a mixture of diphenyloxide and napthalene in its air preheating system and thus brings to the attention of engineers the possibilities of the use of these fluids and other fluids for heat transfer purposes in power plant practice. This is particularly true since the development of diphenyl, diphenyloxide and their kindred products has made high temperature fluids available in commercial quantities and at reasonable prices.

In considering heat transfer problems, there are many fluids which are available, some of which have been extensively used in the lower temperature range and some the use of which has been limited or prohibited due to the cost. It would appear that there is much to be done along the lines which were started at Bremo and that, besides air heating, there is a broad field for the application of this type of heat transfer whether by the use of diphenyl or by other fluids.

There has been much discussion of the possibilities of doing steam reheating by means of a heating fluid. It would appear that this is now among the practical possibilities and that such reheating could be done either externally to the turbine or perhaps in some cases within the turbine case without removing the steam from the turbine. There is also the possibility of doing this reheating more than once. Such an arrangement would not only simplify the reheating problem and improve thermal efficiency of power plants, but would remove the objections of some operating engineers to the lack of flexibility which is more or less inherent in the practice of returning the steam to the boilers for reheating.

It would also appear possible to do the initial superheating in the same manner and thereby remove one of the limiting factors to quick starting of high rating boilers, i.e., the overheating of superheater tubes.

In industrial plants and processes such as paper mills, some kinds of oil refining, salt works, etc. the possibilities of heat distribution with heat transfer fluids are very broad, and in a great many cases economies unquestionably could be effected industrially by bringing the heat more generally to the process and not the process to the heat. It is realized of course that this has been done by means of steam and other heat transfer mediums, but the present advent of higher temperature fluids opens a field as yet not so well explored. In some cases where these fluids can be used to absorb heat from moderately high temperature exhaust gases on existing boilers and thereby utilize energy, otherwise wasted, it would appear possible to make substantial economies without excessive investment.

In considering heat transfer fluids, a word of caution also is not out of place and that is that the characteristics of these fluids should be carefully studied so that they are not subjected to conditions to which they are unsuited. This problem is one which in spite of its possibilities must have sound, constructive and careful engineering, but with such engineering it offers much that is attractive.

R. C. Roe

Design Engineer
Electric Management & Engineering Corporation

EDITORIAL

A. S. M. E. Annual Meeting

A NUMBER of papers and reports relating to various aspects of steam plant design, operation and practice will be presented at the annual meeting of the American Society of Mechanical Engineers, to be held in New York, November 30 to December 4. Among those scheduled are the following: "Ford Motor Company's 1200 lb. Steam Plant Installation"; "Characteristics of a High-Pressure Series Steam Generator"; "Once-Through Series Boiler for 1500 to 5000 lb. Pressures"; "Report of Power Division"; "Fluxing of Ashes and Slags as Related to the Slagging-Type Furnace"; "Progress Reports on Steam Tables"; "Performance of Modern Steam-Generating Units"; "Solubility of Calcium Salts in Boiler Water"; "Inlet Boxes on the Performance of Induced-Draft Fans"; "Determination of Carbonate Hydroxide and Phosphate in Boiler Waters" (Progress Report of Subcommittee No. 8); "Foaming and Priming of Boiler Water"; "The SO_4/CO_3 Ratio for the Prevention of Sulphate Boiler Scale."

These papers and the discussions of them will make available to all interested an up-to-date survey of the principal developments in the field during the past year.

The committees that arrange the programs and select topics and speakers have a large responsibility in that they must decide what subjects are sufficiently important to have consideration in the limited amount of time available and select those capable of giving these subjects adequate presentation. This involves a lot of exacting work and those responsible deserve the appreciation not only of the members in attendance but of all who benefit by the recording of progress and practice in the various fields covered.

One way in which the membership at large can show its appreciation of the work of the program committees is by advising the society of important new developments, completion of research undertakings, etc., that lend themselves to presentation as papers. This type of cooperation will assist those in charge of programs in their difficult task of selecting topics and speakers that will measure up to a standard commensurate with the purpose and principles of the society.

There will be no power exposition in conjunction with the meeting this year due to the fact that this exposition is now on an alternate-year basis. While some may feel that this will detract from the value of this year's meeting, in the long run it will be advantageous to all concerned. The manufacturers who must carry the financial burden of these shows will have more interesting developments to exhibit as the result of a two-year expenditure than would be possible if the annual show plan were continued. It may be confidently expected, therefore, that the 1932 power show will set an exceptionally high standard both in quality and number of exhibits.

Concerning Christmas Remembrances To Customers

THE practice of distributing gifts to customers at the Christmas Season is acceptable or objectionable, depending upon the motives of the giver. Like many other practices, about which there is nothing inherently wrong, it can be done to an excess that is harmful alike to the giver and the receiver, and is injurious to business generally.

We are reminded to comment on this situation through the action of the Purchasing Department of a large public service corporation, which has recently sent out a card expressing its appreciation of the spirit which prompts its suppliers to present Christmas remembrances, but requesting that the practice be discontinued because it adds unnecessarily to overhead and the cost of doing business. Generally speaking, it seems to us that this attitude is well taken and is one that will be increasingly evinced, especially by the larger organizations.

However, there is something to be said in favor of the salesman who wishes to express his appreciation of business patronage by the presentation of appropriate gifts at the Christmas Season. To him this act is merely a gesture of good will and appreciation,—the evidencing of a state of mind which he has a right to feel and express. If in so doing, he increases good will toward himself and his organization, he is adding value to what may be termed the principal asset of any business, regardless of its size or character.

It is when this sort of thing is done to excess—when the giver gives with the idea of creating a sense of obligation—that the practice becomes an abuse. Gifts of this character should be discouraged as they represent a reversion to a type of salesmanship that is definitely out of tune with present-day business methods.

Another angle of this question that suggests itself to us at this particular time is the desirability of applying the funds available for this purpose to aid unemployment relief work. An appropriate way of doing this would be for those firms which ordinarily would distribute Christmas remembrances this year to notify their customers that they were using the funds to be so expended to provide extra employment in their own establishments or as a donation to local unemployment relief. Undoubtedly, the total sum thus made available the country over would aid materially in meeting the present emergency.

Graphical Representation of Engineering Equations

By D. S. DAVIS
Appleton, Wis.

Members of all branches of the engineering profession have occasion to interpret data in graphical form. The matter of selecting the form of graphical representation that is best suited to the use to which particular data are to be put requires a fairly comprehensive knowledge of the nature and construction of the various types of graphs. Such information is presented in the accompanying article in which the author discussed three methods of curve construction, i.e., the natural curve, the straight line and the nomographic, and gives examples of each.

ENGINEERING data are most readily interpreted when presented in convenient graphical form. For even the simplest of two-variable data a good plot is easier to follow than are parallel columns of figures. When three or more variables are involved the meaning of the data when given in tabular form can be grasped only by very careful examination while the significance of the same data, presented graphically, may be apparent at a glance.

The situation is much the same when, as is generally the case, the relationship between the variables is known and has been expressed by a mathematical equation. If ready use is to be made of the equation, voluminous tables must be laboriously calculated in advance or some sort of calculating chart must be prepared. Engineering literature abounds in convenient and cleverly constructed graphs but attention is necessarily directed to the subject matter rather than to the mechanics of the plots. It is the purpose of this paper to describe, in some detail, the construction of several types of chart covering equations of two, three and four variables, illustrating with examples already familiar to the power plant engineer.

The equations most frequently encountered are, in part or in full, of the form,

$$y = a\,x^n + \delta$$

where x and y are the variables and a, n, and δ are constants. In preparing charts for use in solving these equations three general methods may be distinguished: (A) the natural curve, (B) the straight line, and (C) the nomographic. Method (A) plots the variables on ordinary co-ordinate paper while Method (B) uses co-ordinates with special rulings such that the plot becomes a straight line, employing either the familiar logarithmic paper or paper ruled in some manner to suit the individual case. Method (C) utilizes scales which may be cut by a straight line in values satisfying the equation.

Using Method (A), Fig. 1, the equation,

$$y = a\,x^n + \delta$$

plots as a straight line when n = 1, as an hyperbolic curve when n is negative and as a parabolic curve when n is positive. Fig. 1 shows one example of a straight line, one of an hyperbolic curve and two of parabolic curves, one of the latter typifying values of n between zero and unity, and the other, values of n greater than unity. Inspection of the general equation written in logarithmic form,

$$\log (y - \delta) = \log a + n \log x$$

indicates that it will appear as a straight line when log $(y - \delta)$ is plotted against log x or when $y - \delta$ is plotted against x on logarithmic paper, fulfilling the requirements of Method (B). If desired, y may be plotted against x^n and a straight line will result after the manner of Method (B). Method (C) will be discussed in connection with each example.

Two-Variable Equations

Consider Barnes' equation expressing the data of Thomson and Barr relative to the discharge over a triangular weir:

$$V = 2.35\ H^{2.48}$$

where V is the discharge rate in gallons per minute and H is the head, 2 to 7 inches. This equation is seen to be of the form,

$$y = a\,x^n + \delta$$

where y = V, a = 2.35, x = H, n = 2.48, and δ = 0 and, when charted by Method (A), a parabolic curve will result.

Method (A) On ordinary co-ordinate paper lay off the uniform V- and H-scales as in Fig. 2. Using a slide rule, calculate the following table of values and plot V against H, connecting the plotted points with a smooth curve:

TABLE I.

H	2	3	4	5	6	7
$H^{2.48}$	5.6	15.2	31.1	54.1	85.2	124.3
V	13.1	35.8	73.2	127	200	292

Method (B) On ordinary coordinate paper lay off the uniform V-scale as before and a uniform $H^{2.48}$-scale, running from 0 to 124.3. At 5.6 on the latter scale mark the point as H = 2 and at 15.2 mark the point as H = 3 and similarly for H = 4, 5, 6, and 7, Fig. 3. A special plotting paper is thus constructed so that the equation will plot as a straight line. The auxiliary $H^{2.48}$-scale need not appear on the final plot which may easily be traced from the original cross-section paper. To chart the equation draw a straight line from the point (H = 7, V = 292) to the origin.

To avoid construction of a special plotting paper use the familiar single-cycle logarithmic paper and plot the points (H = 2, V = 13.1) and (H = 4, V = 73.2), connecting them with a straight line, A, Fig. 4. Project the intersection of A with the upper V = 100 line to the lower V = 100 line and draw B through this latter point parallel to A. Similarly, draw the dotted line, C, representing the range below heads of 2 in.

Method (C) In using the nomographic method it is desirable to construct a "cycle-chart" for laying off logarithmic scales of various sizes. Lay off a uniform scale 50 cm. in length and draw perpendiculars to this scale at one-centimeter intervals as in Fig. 5. Along the 50-cm. perpendicular lay off a logarithmic scale with the assistance of the C-scale of a "20-in." slide rule and from each point draw a line to the zero point on the uniform scale. The resulting pencil of lines will cut the perpendiculars in logarithmic scales of cycle lengths between 0 and 50 cm.

To chart the equation $V = 2.35\ H^{2.48}$ in the nomographic form fold the cycle chart along the 24.8-cm. perpendicular, place the folded edge along any straight line and mark off the H-scale between 2 and 7 as in Fig. 6. Then fold the chart along the 10-cm. perpendicular, place 13.1 (from Table I) on the folded edge opposite 2 on the H-scale and mark off the V-scale.

Comparison of Methods. Fig. 2, plotted by Method (A), indicates the nature of the relationship between the discharge rate and the head better than does any of the other charts but requires calculation of at least six points and careful drawing of the smooth curve. Fig. 3, Method (B) requires calculation and construction of an auxiliary scale but once this is done the straight line may be drawn with greater ease than the parabolic curve of Fig. 2. Fig. 4, Method (B) is particularly convenient if logarithmic paper is available while Fig. 6, Method (C), results in a compact chart and requires computation of but one value, the starting point.

Three-Variable Equations

Consider Tumlirz's equation for the volume, V, in cubic feet, of one pound of superheated steam at a pressure of P, 50 to 250 lb. per sq. in. absolute pressure and a temperature of t, 300 to 600 deg. fahr. or T, 760 to 1060 deg. fahr. abs:

$$V = 0.596\ \frac{T}{P} - 0.26$$

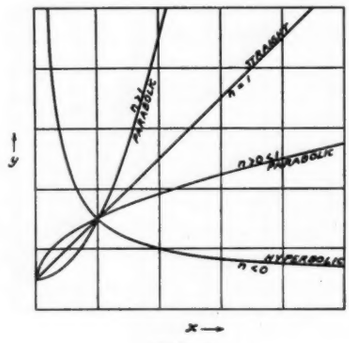

FIG. 1

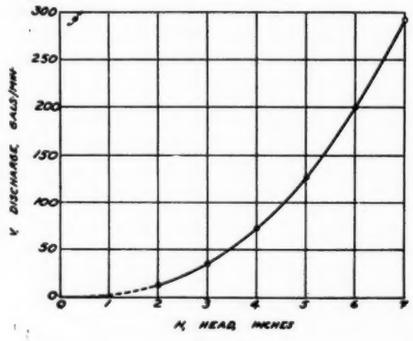

FIG. 2

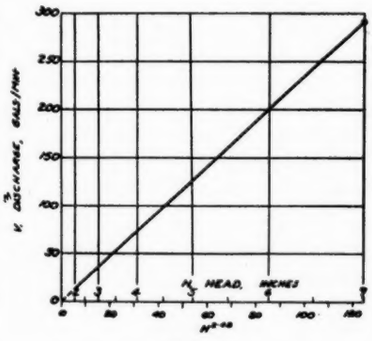

FIG. 3

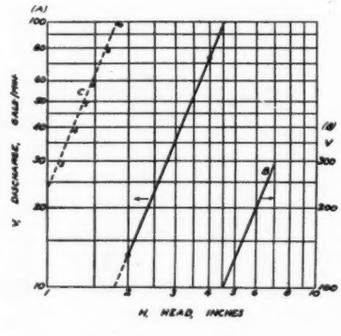

FIG. 4

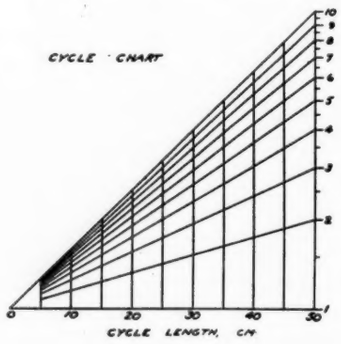

FIG. 5

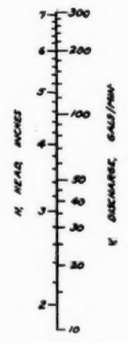

FIG. 6

Method (A) At constant pressure this equation is seen to be of the form, $y = a x^n + \delta$, where $y = V$, $a = \frac{0.596}{P}$, $x = T$, $n = 1$, and $\delta = -0.26$ and by assigning to P the values 50, 75, 100, 125, 150, 200, and 250 the equations of Table II result:

TABLE II.

P	Equation
50	V = 0.0119 T − 0.26
75	V = 0.00795 T − 0.26
100	V = 0.00596 T − 0.26
125	V = 0.00477 T − 0.26
150	V = 0.00397 T − 0.26
200	V = 0.00298 T − 0.26
250	V = 0.00238 T − 0.26

On ordinary coordinate paper these plot as a family of straight lines converging at the point (T = 0, or t = -460; V = -0.26) which lies off the chart, Fig. 7. Each line is marked with the value of P to which it corresponds.

At constant temperature the Tumlirz equation is again seen to be of the form, $y = a x^n + \delta$, where $y = V$, $a = 0.596$ T, $x = P$, $n = -1$ and $\delta = -0.26$ and by assigning to T the values 760, 860, 960, and 1060 corresponding to 300, 400, 500 and 600 deg. fahr. the equations of Table III result:

TABLE III.

t	Equation
300	$V = \frac{453}{P} - 0.26$
400	$V = \frac{513}{P} - 0.26$
500	$V = \frac{572}{P} - 0.26$
600	$V = \frac{632}{P} - 0.26$

On ordinary coordinate paper these plot as a family of hyperbolas asymptotic to P = 0 and to V = -0.26, Fig. 8. Each curve is labelled with the value of t to which it corresponds.

Method (B) On ordinary coordinate paper lay off the uniform V-scale as before and a uniform $\frac{1}{P}$ scale, the latter running from 0 to 0.020. At 0.020 on the reciprocal P-scale mark the point (P = 50) and at 0.010 mark the point (P = 100) etc., thus constructing a special plotting paper so that the equations of Table III plot as a family of straight lines converging at the point (P = ∞, V = -0.26), Fig. 9. Each constant temperature line may be drawn by connecting a calculated point with the convergence point.

To avoid construction of a special plotting paper plot V + 0.26 (at the right in Fig. 10) against P on logarithmic paper, assigning values to T as before, and arriving at a family of parallel constant temperature lines. Another type of special plotting paper may be made from logarithmic paper by retaining the same logarithmic scale for P and constructing a special log (V + 0.26) — scale for the ordinates. V, at the left in Fig. 10, is then plotted directly against P, resulting in exactly the same parallel lines as before. To avoid confusion the horizontal rulings are indicated only at the right and left edges of the chart.

Method (C) In preparing a nomograph note that the logarithmic form of the Tumlirz equation is log (V + 0.26) = log 0.596 + log T − log P. Draw parallel lines at a convenient distance apart, say 12 cm., Fig. 11, and on one lay off the logarithmic P-scale using the cycle chart folded at, say the 25-cm. perpendicular. On the other, and in the opposite direction (since the signs of log T and log P are different) lay off the logarithmic T-scale using a cycle length of, say 50 cm. Draw the V-line parallel to and between the P- and T-scales so that the distances of the V-line from the P- and T-scales are in the ratio of the respective cycle lengths of these scales, that is, the V-line will be located 4 cm. from the P-line and 8 cm. from the T-line, since 4 : 8 = 25 : 50. Using a cycle length equal to the product of the other cycle lengths divided by their sum, that is, $\frac{25\ (50)}{25 + 50}$ or 16.66...cm. lay off the V-scale in the same direction as the P-scale (since log (V + 0.26) and log P have the same sign) using as a starting point the calculated value of 3.81 for V + 0.26 located by aligning the points (P = 150) and (t = 500). The V-line is scaled in values of log (V + 0.26) but marked in values of V while the t-line is marked in values of t though scaled in values of log (t + 460) or log T. A straight line will cut the three scales in values satisfying the Tumlirz equation.

Comparison of Methods. Of the various charts of the Tumlirz equation Fig. 8, Method (A) best reveals the nature of the relationship between the variables but the hyperbolas require the calculation of more points than do the convergent straight lines of Fig. 7, Method (A) and Fig. 9, Method (B) or the parallel lines of Fig 10, Method (B). On the other hand Fig. 9, Method (B) and the direct plotting of V vs. P of Fig. 10, Method (B) require the construction of special plotting paper, although this is easily done. Plotting of V + 0.26 vs. P on logarithmic paper, Fig. 10, Method (B) is simplest but Figs. 7, 8, 9, and 10 all depend upon interpolation between curves for either temperature or pressure values. In the case of the nomograph, Fig. 11, Method (C), each variable has an easily constructed scale of its own, greatly facilitating interpolation. The nomograph is free of all coordinate lines but requires a straight edge for its use.

As an additional example of the various methods of charting three-variable expressions consider the equation given by B. J. Cross in the August, 1930, issue of COMBUSTION magazine for Q, the rate of

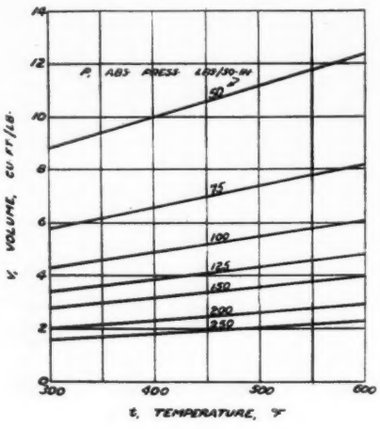

FIG. 7

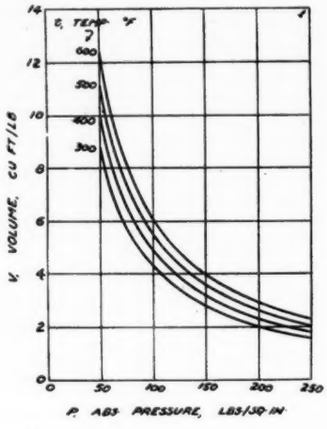

FIG. 8

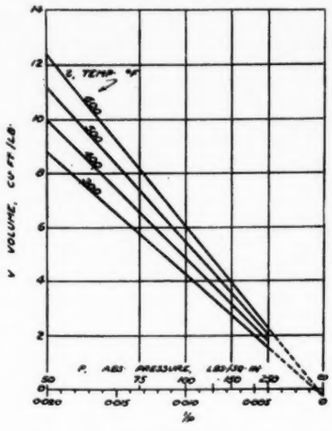

FIG. 9

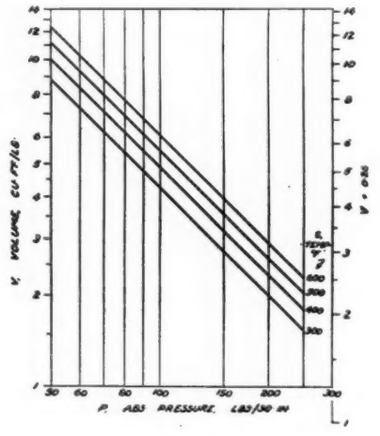

FIG. 10

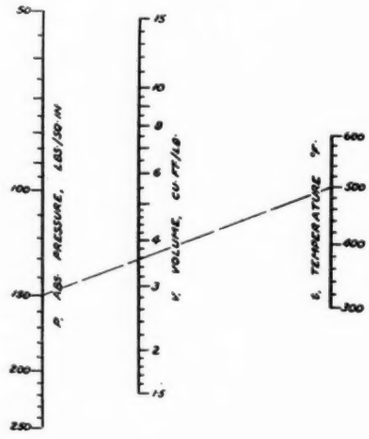

FIG. 11

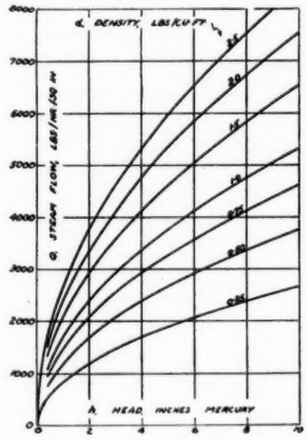

FIG. 12

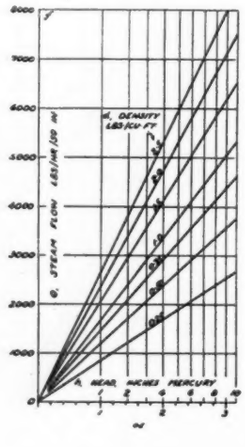

FIG. 13

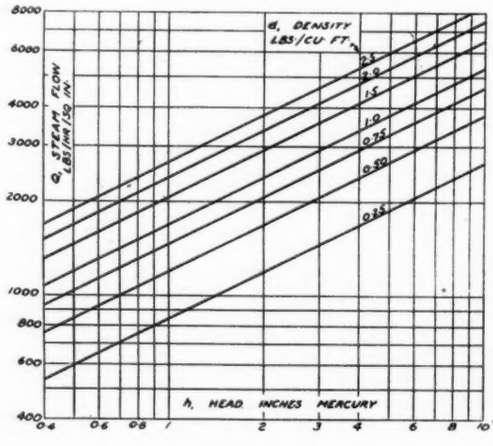

FIG. 14

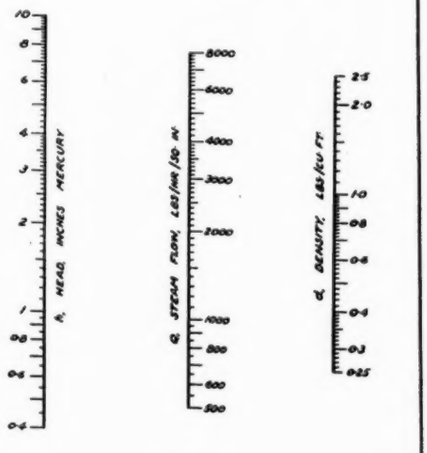

FIG 15

flow of steam, lb. per hr. per sq. in. effective area under a differential head equivalent to h, 0.4 to 10 in. of mercury and at a density of d, 0.25 to 2.5 lb. per cu. ft.

$Q = 1683 \sqrt{h\,d}$ or $Q = 1683\ h^{0.5}\ d^{0.5}$

Method (A) At constant density the steam flow equation is seen to be of the form $y = a\ x^n + \delta$ where $y = Q$, $a = 1683\ d^{0.5}$, $x = h$, $n = 0.5$, and $\delta = 0$ and by assigning to d the values 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, and 2.5 the equations of Table IV result.

On ordinary coordinate paper these plot as a family of parabolas with the origin as the common vertex, as in Fig. 12 which is similar to the chart given by Cross.

Method (B) On ordinary coordinate paper lay

off the uniform Q-scale as before and a uniform $h^{0.5}$-scale, the latter running from 0 to 3.17. At 1 on the $h^{0.5}$-scale mark the point (H=1) and at 2 mark the point (H=4), thus constructing a special plotting paper so that the equations of Table IV plot as a family of straight lines converging at the origin, Fig. 13.

TABLE IV.

d	Equation
0.25	$Q = 842\ h^{0.5}$
0.50	$Q = 1190\ h^{0.5}$
0.75	$Q = 1456\ h^{0.5}$
1.00	$Q = 1683\ h^{0.5}$
1.50	$Q = 2060\ h^{0.5}$
2.00	$Q = 2380\ h^{0.5}$
2.50	$Q = 2661\ h^{0.5}$

Construction of special plotting paper may be avoided by plotting Q vs. h directly on logarithmic paper, using the equations of Table IV, and arriving at a family of parallel constant density lines, as in Fig. 14. In exactly the same manner plots of Q vs. d may be prepared by Methods (A) and (B), resulting in families of constant head lines.

Method (C) Preparatory to constructing a nomograph note that the logarithmic form of the steam flow equation is

$$\log Q = \log 1683 + 0.5 \log h + 0.5 \log d$$

Draw parallel lines a convenient distance apart, say 12 cm., Fig. 15, and on one lay off the logarithmic $h^{0.5}$-scale using a cycle length of 25 cm. for $h^{0.5}$ which amounts to scaling the line directly in values of h using a cycle length of 0.5 (25) or 12.5 cm. On the other line and in the same direction (since the signs of the h and d terms are the same in the logarithmic equation) lay off the logarithmic $d^{0.5}$-scale using a cycle length of 25 cm. for $d^{0.5}$ but actually scaling this line directly in values of d using a cycle length of 12.5 cm. Draw the Q-line midway between the h and d-scales since these have equal cycles and lay off the Q-scale with a cycle length of $\frac{25\ (25)}{25 + 25}$ or 12.5 cm., starting at Q = 1683 found by aligning the points (h = 1) and (d = 1). A straight line will cut the three scales in values satisfying the steam flow equation.

Comparison of Methods. Again it is seen that Method (A) leads to a chart, Fig. 12, which reveals in part, at least, the nature of the expression connecting the variables but which is somewhat laborious to construct. The straight line charts, Figs. 13 and 14, of Method (B) are much easier to prepare but are really not as simple as the nomograph of Method (C), Fig. 15.

Four-Variable Equations

Consider the four-variable equation,

$d = 0.013 \sqrt{D\ P\ L}$ or $d^2 = 0.000169\ D\ P\ L$

where d is the proper diameter of a piston rod in inches when D is the diameter of the piston, 12 to 24 in.; L is the length of the stroke, 12 to 60 in.; and P is the maximum absolute steam pressure, 80 to 150 lb. per sq. in.

Method (A) Let $s = D\ P$ (a)

Then $d^2 = 0.000169\ S\ L$ (b)

Equation (a) when written as $P = \frac{S}{D}$ is seen to be of the form $y = a\ x^n + \delta$ where $y = P$, $a = S$, $x = D$, $n = -1$, and $\delta = 0$ and by assigning to S the convenient values of 1000, 1500, 2000, 2500, 3000, 3500, and 4000 the equations of Table V result.

TABLE V.

S	Equation
1000	$P = \frac{1000}{D}$
1500	$P = \frac{1500}{D}$
2000	$P = \frac{2000}{D}$
2500	$P = \frac{2500}{D}$
3000	$P = \frac{3000}{D}$
3500	$P = \frac{3500}{D}$
4000	$P = \frac{4000}{D}$

On ordinary coordinate paper these plot as a family of hyperbolas asymptotic to the P and D axes, Fig. 16. To avoid confusion the coordinate rulings are not carried across the chart but are indicated on the outer boundaries. The inner boundaries carry the centimeter scales of the original coordinate paper.

Equation (b) is also seen to be of the form $y = a\ x^n + \delta$ where $y = d^2$, $a = 0.000169\ S$, $x = \frac{1}{L}$, $n = -1$, and $\delta = 0$. Just below the centimeter scale at the top of the chart mark off a uniform $\frac{1}{L}$-scale and opposite 0.02 on the $\frac{1}{L}$-scale mark the point (L = 50) and mark the point (L = 20) opposite 0.05 on the $\frac{1}{L}$-scale, etc. The d-scale at the right must be constructed of a size such that the same values of S may be retained for the hyperbolas. Note that solution of equation (b) shows that $d^2 = 27.04$ when L = 40 and S = 4000 and that the line L = 40 intersects the S = 4000 hyperbola at a point 8 cm. above the lower horizontal axis. One unit in d^2 is thus seen to be represented by $\frac{8}{27.04}$ or 0.296 cm. and the d-scale may be laid off by noting that the point (d = 6) corresponding to

$d^2 = 36$ is located at a distance of 0.296 (36) or 10.65 cm. from the origin.

The use of the completed chart is illustrated as follows: What is the proper piston rod diameter when the diameter of the piston is 20 in., the stroke is 30 in., and the maximum pressure expected is 140 lb. per sq. in. absolute? Following the dotted line, proceed upward from 20 on the D-scale to the dotted line drawn toward the right from 140 on the P-scale. From this intersection follow downward and parallel to the nearest hyperbola to the dotted line representing 30 on the L-scale. From this point proceed horizontally to the d-scale and read the desired value as 3.75 in.

Method (B) Considering P constant, equation (a), $S = D\ P$, may be seen to be of the form $y = a\ x^n + \delta$ where $y = S$, $a = P$, $x = D$, $n = 1$, and $\delta = 0$. By assigning to P the values 80, 100, 120, 140, and 160 the following equations result: $S = 80\ D$, $S = 100\ D$, $S = 120\ D$, $S = 140\ D$, and $S = 160\ D$. On ordinary coordinate paper these plot as a family of straight lines converging at the origin, Fig. 17.

Considering L constant, equation (b), $d^2 = 0.000169\ S\ L$, when written as $S = \frac{d^2}{0.000169\ L}$ is seen to be of the form $y = a\ x^n + \delta$ where $y = S$, $a = \frac{1}{0.000169\ L}$, $x = d$, $n = 2$, and $\delta = 0$. On the continuation of the D-axis lay off the uniform d^2-scale above the line and the d-scale below the line, locating $d = 6$ opposite $d^2 = 36$, etc. The position of the $L = 60$ line, for instance, may be located by solving equation (b) for S when $d^2 = 16.9$ and $L = 60$ plotting the value, 1667, so calculated and connecting the plotted point with the origin by a straight line. In this way another family of straight lines converging at the origin results. The auxiliary S-scale need not appear on the finished chart. The use of Fig. 17 is shown as follows, using the values of the previous illustration: Trace the dotted $D = 20$ line to the heavy $P = 140$ line and thence horizontally to the heavy $L = 30$ line and then downward to the d-scale where the desired value is read as 3.75 in.

For plotting on logarithmic paper it is convenient to split the original equation into two parts:

$$R = 0.000169\ D\ P \qquad (1)$$

$$\text{and } d^2 = R\ L \qquad (2)$$

and, in the case of equation (1), to plot D against P for values of R of 0.1 to 1.0 in steps of 0.1, obtaining a series of parallel lines sloping downward to the right and shown dashed in Fig. 18. At right angles to this set of lines draw in another set as shown in the figure by the dashed lines sloping downward to the left. Together the two sets of dashed lines form another but smaller square of logarithmic paper. For constant values of d, in the case of equation (2), plot R against L on the new coordinates, arriving at a family of parallel lines spaced logarithmically. As an illustration of the use of the chart, and retaining the values of the

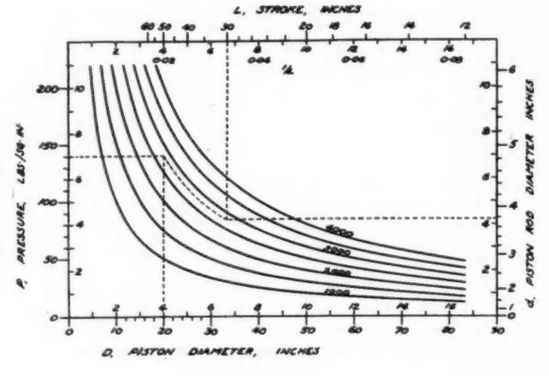

FIG. 16

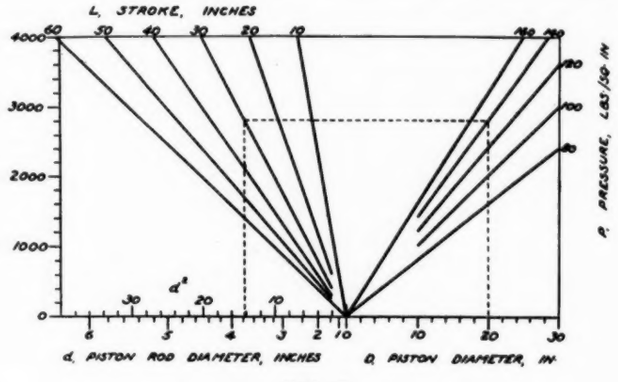

FIG. 17

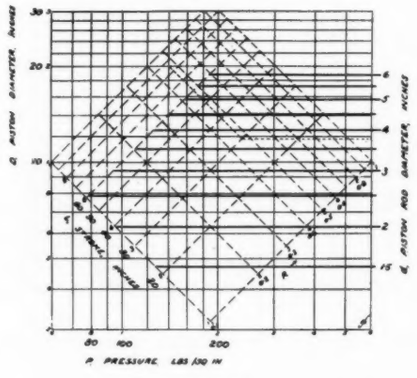

FIG. 18

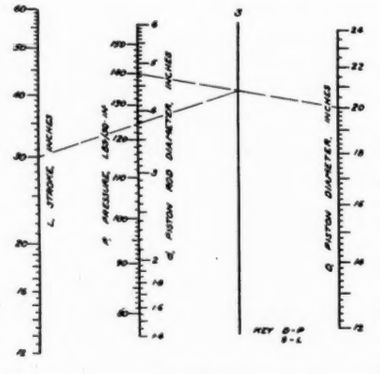

FIG. 19

previous examples, follow the P = 140 line to the D = 20 line and proceed from this intersection along the dotted line to the dashed L = 30 line and interpolate the value of d as 3.75 in. between the heavy d-lines.

Method (C) Preparatory to constructing the nomograph of Fig. 19 write equations (a) and (b) in the logarithmic form,

$$\log S = \log D + \log P \qquad (a)$$

and $2 \log d = \log 0.000169 + \log S + \log L$ (b)

Construct a nomograph for equation (a) as in the case of a two-variable expression spacing the P and D axes a convenient distance of 10 cm. apart and choosing cycle lengths of 50 cm. for each. The S-line is located midway between the D and P-lines and if scaled it would require a cycle length of 25 cm. Then construct a nomograph for the other two-variable equation, (b), choosing the cycle length for the L-scale to equal that for the above S-line, 25 cm., and spacing these lines 10 cm. apart for the sake of a compact chart. Superimpose the second nomograph upon the first so that the two S-lines coincide and draw the d-line midway between the L and S-lines, scaling in values of d^2 using a cycle length of 12.5 cm., or, more easily, scaling directly in values of d, using a cycle length of 25 cm. A starting point for the d-scale may be found by substituting suitable values of D, L and P in the original equation and aligning these as shown by the dashed index lines which illustrate the use of the chart when D = 20, P = 140, and L = 30. Following the key, connect 20 on the D-scale with 140 on the P-scale and from the intersection of the dashed line with the S-axis draw a line to 30 on the L-scale, cutting the d-scale in the desired value, 3.75 in.

Comparison of Methods. Method (A) leads to a fairly complex chart, Fig. 16, which is tedious to construct, requires careful drafting, and which would present a maze of coordinate rulings if all were carried through. Figs. 17 and 18, prepared by Method (B) are simpler to draw and to read but even these can not compare in simplicity of construction and use with the nomograph of Fig. 19, Method (C).

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Air Conditioning For Homes

The American Blower Company, Detroit, Mich., has just issued a most interesting announcement relative to the development of an air conditioning unit suitable for small as well as large residences. One of the units has been installed in an 8-room frame house at Highland Park, Mich., for more than a year, with excellent results.

It is claimed that this equipment can maintain a uniform temperature and humidity indoors the year round, which means that the house temperature in the hottest days of summer can be held within a range of from 70 to 80 deg. fahr.

Carl Stripe Resigns Editorship of Combustion

Carl Stripe, who has been Editor of COMBUSTION since the first issue was published in July, 1929, has resigned to establish a new monthly publication, to be known as "Steam Plant Engineering." Mr. Stripe has had a long identification with the steam plant field in various capacities. As Field Engineer for the Stoker Department of the Westinghouse Electric & Manufacturing Company, and later as Sales Engineer, District Sales Manager and Publicity Manager of Combustion Engineering Corporation, he has acquired a broad background of knowledge relative to the design and operation of steam power plants, as well as the sales problems of manufacturers of steam plant equipment.

Charles McDonough, who has been associated with Mr. Stripe in the publishing of COMBUSTION, will succeed him as Editor.

•

Niagara-New York Interconnection Approved

The Public Service Commission of New York has granted final authorization to complete the interconnection between the systems of the New York Edison Company and the Niagara Hudson Power Corporation. The New York Power & Light Corporation, a Niagara Hudson subsidiary, will start work immediately on the completion of the 110,000-volt line. This undertaking will provide work for 1500 men.

As a result of this interconnection, the Niagara Hudson system will send hydro-electric power to meet New York peak loads, and the Edison system will provide steam power when needed by plants in the upper part of the state. It is estimated that operating economies up to $200,000 to $400,000 a year will be effected, and further savings in plant investment of $10,000,000 by the Edison Company and $4,000,000 by the Niagara Hudson Company are expected to be realized. The section to be completed is 75 miles long and will cost $7,500,000.

•

The Foster Wheeler Corporation announces the opening of a branch office in Washington, D. C. This office will be equipped to handle inquiries for stationary and marine power plant equipment, and in general all products of the Corporation.

Mr. J. S. Malseed has moved from New York to Washington and will be in charge of the new office, which is located at 726 Jackson Place, N.W.

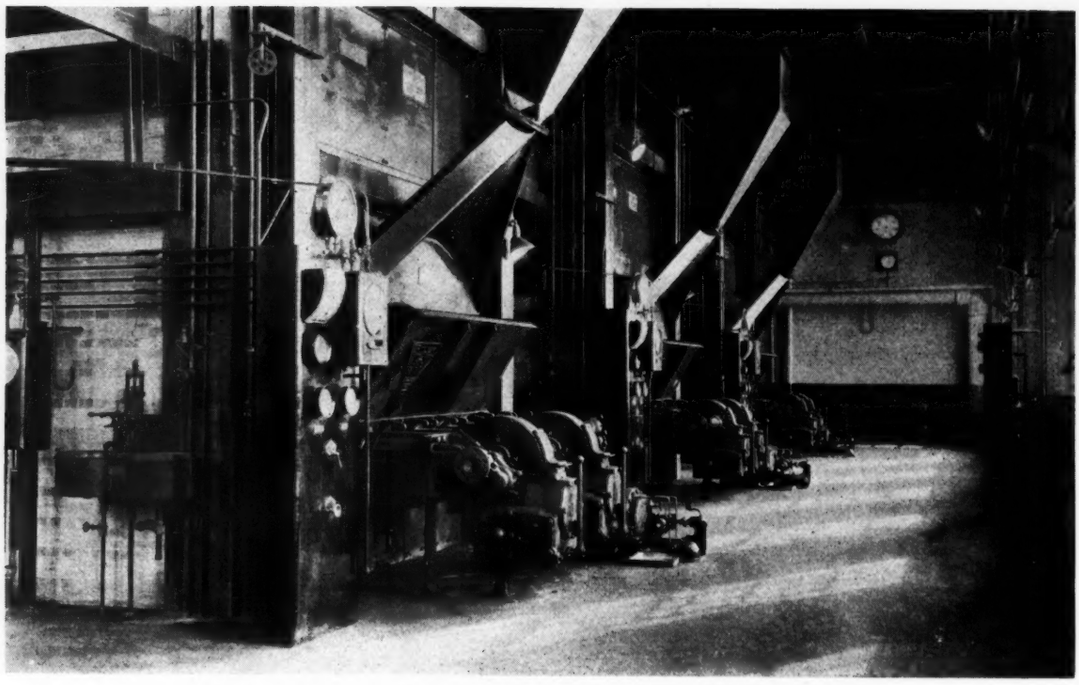

Fig. 1—Boiler room, M. J. Whittall Associates, Ltd., Worcester, Mass.

Combustion Control Co-ordinates New Power Plant

By K. R. WARRINGTON
Mechanical Engineer,
Francis J. Sill, Westboro, Mass.

This is an interesting example of the ability of a modern combustion control system to maintain high overall efficiency with a fluctuating load. The working hours of the carpet mill served by this installation are such that it is necessary to bring the boilers from banked condition to peak load twice in seven hours to meet the heating requirements of the dyehouse, yet an average overall boiler efficiency of 79.5 per cent is maintained.

•

THE M. J. Whittall Associates, Ltd., of Worcester, Mass., makers of the famous Anglo-Persian rugs, placed in operation last December a new power plant for generating steam and electricity for supplying the carpet mills and all buildings in connection with the mills.

Three boilers with integral economizers were installed, each unit with a combined heating surface of 7228 sq. ft., fired by a turbine-driven, underfeed stoker of the multiple retort type, burning bituminous coal. Air is supplied to each stoker by an individual turbine-driven forced draft fan. The furnaces are of solid refractory design, with water-cooled rear walls.

Steam from the boilers is collected in a manifold main steam header for supplying turbine generators, auxiliary turbines, etc., at a pressure of approximately 175 lb. gage and 100 deg. fahr. superheat.

A 1500 kw. turbo-generator was installed to accommodate the present maximum mill electric loads, and a 300 kw. turbo-generator was installed to accommodate the overtime night loads, etc.

The steam load requirements equal or exceed the electric load during the greater part of mill operation, as all steam necessary to generate electricity during mill operation is utilized in the mills at approximately 20 lb. gage.

Both turbines are the extraction, condensing type, extracting steam at approximately 20 lb. gage to a process header for mill distribution.

An auxiliary line from the main steam header to the process header was installed and is for use

when the turbines are not extracting sufficient steam for mill demand, or when the turbines are shut down during mill demand for steam. The auxiliary line is controlled by a pressure-reducing valve, reducing steam from main header pressure to approximately 20 lb. gage, or the process header back pressure.

Individual coal scales, steam flow—air flow meters, draft gages, CO_2 meters, a Venturi meter, and the usual recording and indicating thermometers and pressure gages were installed to allow the operators to keep records of the performance of each boiler and main turbine.

At the time equipment for the new power plant was being purchased, it was decided to install a complete system of automatic combustion control for the three boilers, for the following reasons:

a. Increased efficiency over hand operation. Maintenance of equal rates of combustion on all boilers in service, regardless of fuel bed resistance, and regulation of the fuel and air supply in accordance with the load on the plant.
b. Reduction of boiler room labor.
c. Prevention of unnecessarily high combustion rates and thereby lessened maintenance on the boilers, boiler settings and stokers.
d. Prevention of excessive production of smoke. (The plant is situated near a thickly settled area.)

The Hagan system of automatic combustion control was selected, and, as installed, consists of the following units:

1. A master panel, including a master regulator, sending device, station pressure compensator, manual control and indicating gages.
2. Individual boiler panels, each including boiler rating compensator, manual control and indicating gages.
3. Receiving regulators.
4. Individual boiler combustion controllers for compensating draft.
5. Air compressor and storage tank for independent air supply to operate combustion control system.
6. Control valves for the forced draft fan and stoker turbines.

The master regulator responds to changes in the main steam header pressure and controls a sending device which transfers an impulse through the individual boiler gageboard compensating relays to the receiving regulators controlling the speed of the stokers, forced draft fans and the position of the boiler uptake dampers. On the master control panel provision is made for increasing or decreasing the plant steam pressure, or for placing the entire plant under manual control. No provision is made at the master panel for adjusting one boiler independently of another. However, provision is made at each boiler panel for individual adjustment and for placing any boiler on manual control.

The individual combustion controllers adjust the

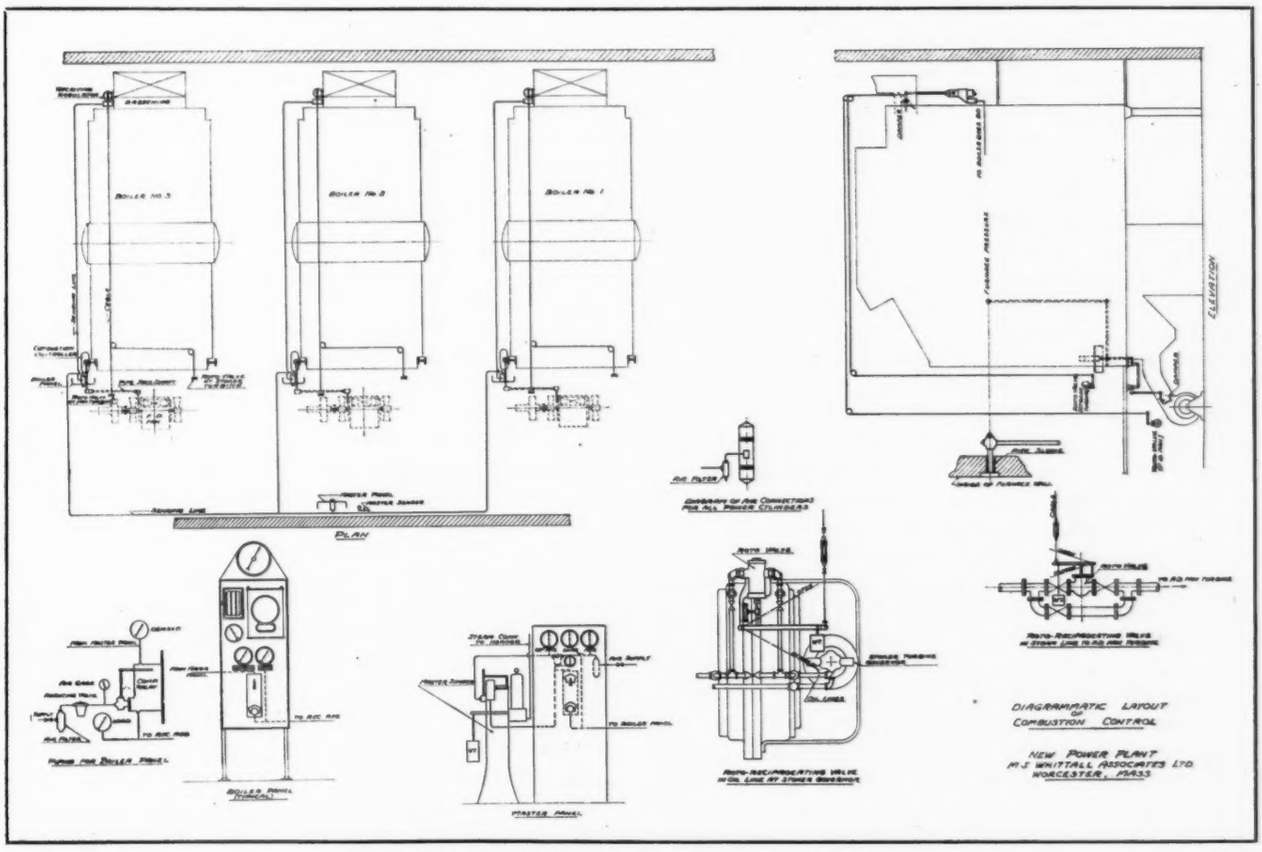

Fig. 2—Diagrammatic layout of combustion control system.

forced draft fan dampers to compensate for varying fuel bed resistances and maintain the correct draft over the fires.

The sending system consists of a small pipe line carrying air under pressure. There is no flow through this line. The master regulator in responding to pressure changes in the main steam header varies the pressure over a range in the sending system. For every position of the master there is a definite pressure in the sending system. To this system is connected the receiving regulators that take the same position as the master regulator

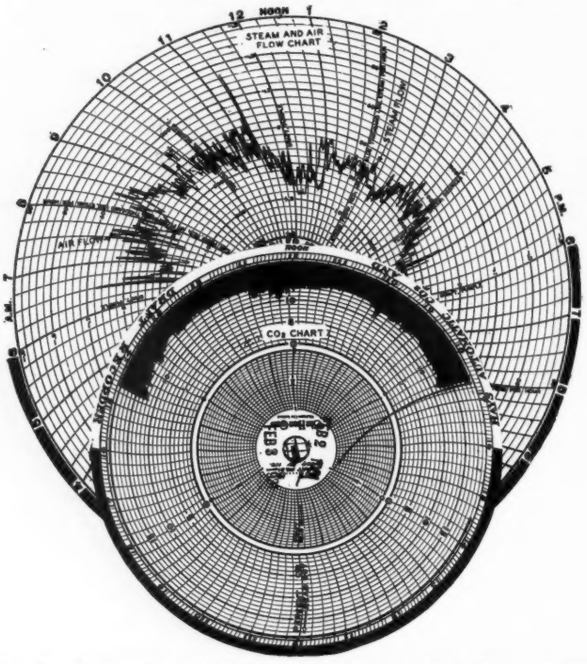

Fig. 3—Upper chart (No. 1) shows steam and air flow. Lower chart (No. 2) shows CO_2.

for every pressure change in the main steam header. The receiving regulator on each boiler operates its own sending system and transmits the impulse received from the master regulator to the stoker turbine, forced draft fan turbine and boiler uptake damper.

The combustion controller on each boiler is actuated by the furnace pressure, and the movement of the controller mechanism controls the forced draft fan damper independent of the master regulator and other boilers.

An auxiliary air line from the station air compressor is connected to the discharge of the combustion control air compressor to insure the air supply to the combustion control system.

During preliminary operation the boilers were hand operated, to enable the operators to become familiar with the boiler room equipment.

Inasmuch as the working hours of the mills were from 8:00 P. M. to 12:00 M., and 1:00 P. M. to 5:00 P. M., it was necessary to bring the boilers from a banked condition to peak load twice in seven hours to accommodate the peaks occurring when heating water in the dyehouse at the beginning of each working period. Wide range swings were indicated by the boiler room master pilot gage, due to the pressure reducing valve in the auxiliary line from the main steam header to the process header opening and closing to maintain the desired process header pressure.

After the boilers had been operated by hand for several days, it was decided to change over the operation to automatic control.

The combustion control system was calibrated after determining experimentally the actual relations between the damper positions or draft and the stoker speeds under actual operation.

Although the master regulator will respond to a fraction of one pound pressure change, it can be made to take a full stroke on a pressure range as small as one pound, or by means of adjustable compensation this pressure range can be increased to 5, 10, 15, 20, 25 lb., or whatever amount best accommodates the plant conditions. For every plant there is a relation between the range of compensation and the nature and extent of load fluctuations that will give the best over-all condition of regulation. The master regulator was set so that variations in pressure in the main steam header would not exceed 7 lb. to accommodate the new power plant load fluctuations.

All adjustments necessary were made in three days, and the boilers were then placed definitely on automatic control. Approximately one month later, the records of operation were reviewed and analyzed, after which a minor adjustment for calibration was made. Since that time no other adjustments for calibration of the combustion control system have been necessary.

This complete installation of combustion control has now been in satisfactory service for over nine months and has accomplished every purpose for which it was installed, as follows:

a. The average overall boiler efficiency has been 79.5 per cent. Chart No. 1, Fig. 3, shows the steam flow—air flow and clearly designates how closely the lines follow together during mill operation regardless of load swings. The nicety with which the fuel and air regulation is maintained is shown by Chart No. 2 as recorded by the CO_2 meter on the same boiler and during the same period of operation as Chart No. 1.
b. One fireman each shift supervises boiler room operation which demands approximately one-half of his time.
c. Recently each boiler unit was taken out of service and inspected, and the boilers, stokers and boiler settings were found to be in excellent condition.
d. A wisp of white or gray smoke discharging from the chimney is the only visible combustion product during normal operation.

The maintenance required on the different units of apparatus has included only an occasional oiling and inspection by the plant service man.

The new power plant was designed and constructed by Francis J. Sill, Consulting Engineer, Westboro, Mass.

New Brazil Plant Burns Low-Grade Coal at High Efficiency

The author describes the steam-electric plant recently installed for the city of Porto Alegre, Brazil. This plant uses the pulverized fuel method of firing for burning local lignite of low heating value and containing 35 to 40 per cent ash, 8 to 14 per cent moisture and considerable stone and pyrites. While the maintenance on mills, fans, etc., is high, good overall efficiency is obtained and operating results show substantially better economy than could be secured by using a good grade of imported coal. Interesting figures are given on mill maintenance, power costs and amortization charges.

By C. H. S. TUPHOLME,
LONDON

THE rapid development of Porto Alegre, the capital of the state Rio Grande do Sul, and the poor condition into which the small existing power plants in this city had been allowed to get, induced the interested authorities to build a new steam power plant producing electricity for lighting and street car service. The existing electric system was principally operated with direct current: the introduction of alternating current made a complete change necessary.

The new power station is located on the shore of the Lagoa dos Patos at the end of a peninsula, on which part of the town is built. The situation is a favorable one, in that the coal can be shipped direct to the power plant on barges, and an ample supply of water is available for the condensing plant of the steam turbines.

Before entering into details on the power plant equipment, it may be of interest to mention the special coal conditions. The coal produced by the mines of San Jeronymo and Butia, some hours away from Porto Alegre, is a stratified lignite mixed with stone and pyrites. Though many industrial firms in that part of Brazil use British coal, this plant had to employ Brazilian fuel on account of economy. The high price of British coal is generally compensated by better combustion and lower cost for handling and also for maintaining the furnace. The unfavorable characteristics of this Brazilian coal can be seen from the analysis below, which was carried out by the Federal Laboratory for Testing Materials, Department of Technical Chemistry and Fuels, of the Technical University in Zürich.

Analysis No.	1	2	3
Net calorific value, B.t.u. per lb.	7130	6215	6370
cal. per kg.	3960	3453	3539
Moisture, per cent	8.5	13.7	7.8
Ash, per cent	35.5	35.6	39.4
Fixed carbon, per cent	30.4	26.7	29.0
Volatile matter, per cent	25.6	24.0	23.8
	100.0	100.0	100.0
Sulphur, per cent (Separate determination)	0.5	1.3	4.2

The ash content is excessive, largely owing to the stone mixed with the coal layer. The moisture content is very high, which represents also an inconvenient characteristic. These two components lower the calorific value so much that the application of a mechanical stoker would be difficult on account of the large grate dimensions necessary. The installation of driers was considered in order to reduce the excessive moisture content, since it is a well-known fact that the operation of pulverizing mills is handicapped by wet coal, and the power consumption is much increased by the moisture. It had been decided to reduce the moisture content down to about 2 per cent. However the proprietors of the plant finally decided against the use of drier equipment. The only favorable characteristic of the fuel is the high content of volatile matter. Besides the sulphur content, the coal contains pyrites; needless to say, these components cause serious trouble, especially as regards clinker formation. Preliminary analysis showed the variability in quality of the coal. Net calorific values of 10,000, 9,000, and 8,000 and 7,500 B.t.u. were indicated, whereas the moisture content specified varied between 12 and 4 per cent and the ash between 23 and 35 per cent.

The old plants of the electricity company burned the same fuel on grates, but the results were not satisfactory. The clinker was the main cause of trouble and the ash and clinker contained much unburned coal. These unsatisfactory experiences decided the company to abandon this system and to choose pulverized coal firing in the hope of get-

ting better combustion and consequently a higher efficiency than with mechanical stokers. For the above-mentioned reasons, and considering the dimensions of the units, the adoption of pulverized coal firing was the right solution for this kind of coal. The efficiency foreseen, much surpassing the efficiency of the mechanical stoker, has been fully verified in practice as will be seen.

The power plant building is 260 ft. long by 118 ft. wide, and the height of the boiler room above ground amounts to 93 ft. The whole of the electric equipment is located in the power house. The buildings are mainly situated on ground reclaimed from the lake by filling in. The plan and the longitudinal and cross sections, shown in Fig. 2, give a general idea of the arrangement.

The boiler plant with its auxiliaries has been supplied by Sulzer Brothers, Wintherthur, whereas the turbo-alternators and accessories, as well as complete electrical equipment come from the Ateliers de Construction Oerlikon.

The plant comprises:

2 Turbo-alternators, also condensers and auxiliaries and complete switchboard from "Oerlikon."

Steam conditions at turbine inlet valve, 285 lb. per sq. in.	660 deg. fahr.
Normal output per unit	5000 kw.
Maximum output per unit	6250 kw.
Speed	3000 r.p.m.
Electric supply	6600 volts, 50 cycles

5 Sulzer upright water-tube boilers, of the single-bank type, with pulverized coal firing, superheaters and economizers.
Steam conditions, 315 lb. per sq. in., 710 deg. fahr.
Heating surface of each boiler unit:—

Boiler tube bank	3500 sq. ft.
Water screen in the furnace	140 sq. ft.
Total	3640 sq. ft.
Economizer	2600 sq. ft.
Volume of the combustion chamber (between boiler tube bank and water screen) about	4400 cu. ft.

2 Induced draft installations, each consisting of one centrifugal fan, driven by means of two 60 hp. motors at 720 r.p.m., and a steel chimney.
5 Coal mills, Farner system (1 mill for each boiler), working without pulverized coal storage, each direct coupled to an electric motor of 110 hp. running at 970 r.p.m.
3 Centrifugal boiler-feed pumps (two with electric drive, one with turbine drive). Capacity per unit, 8000 Imperial gal. per hr. Manometric head, 805 ft.

	Electric pump	Pump with turbine drive
Speed	2900 r.p.m.	4600 r.p.m.
Power required	52 hp.	60 hp.
Output of the motor or turbine	60 hp.	65 hp.

Distilling plant, Balcke system. Capacity 1320 Imperial gal. per hr.
Coal breaker, hoist and transporting plant, capacity 20 tons per hour.
Measuring instruments for boiler plant:—
1 Coal weighing meter for each boiler.
1 Water meter in the feed piping.
Thermometers for water at inlet and outlet of the economizers.
Pressure gages.
Electric thermometers with remote indicators for superheated steam and flue gas at outlet of the economizer.
CO_2 indicators and recorders.

The four furnace walls are fitted with air ducts for cooling the refractory material and at the same time preheating the combustion air. The air circulation through the rear and front walls is admitted directly into the combustion chamber, whereas the air preheated in the side walls is drawn partly through the mill, and partly through the auxiliary fan supplying the secondary air for the burners.

A water screen is arranged in the lower part of the combustion chamber in order to prevent the formation of clinker. This screen is directly connected to the boiler by means of large up and down-comers. The down-comers connect the lower boiler drum with the rear header of the water screen; the up-comers connect the front header of the screen with the upper drum.

The distilling plant comprises four evaporators and one condenser working in series with total recuperation, i.e., the steam produced by evaporation of raw water is condensed in the next evaporator. The first evaporator is heated by means of live steam, throttled down to 70 lb. per sq. in. absolute, whereas the steam produced in the fourth evaporator joins the condenser, which is cooled with raw water. From this condenser the raw water is distributed in parallel into the four evaporators. When working with a pressure of 70 lb. per sq. in. absolute in the first evaporator and about 28 lb. per sq. in. absolute in the second and with 80 per cent vacuum in the condenser, the plant produces 1320 Imperial gal. of distilled water per hour. The distilled water and the feedwater leaving the condensers of the turbine mix in the tank connected to the suction branch of each boiler-feed pump.

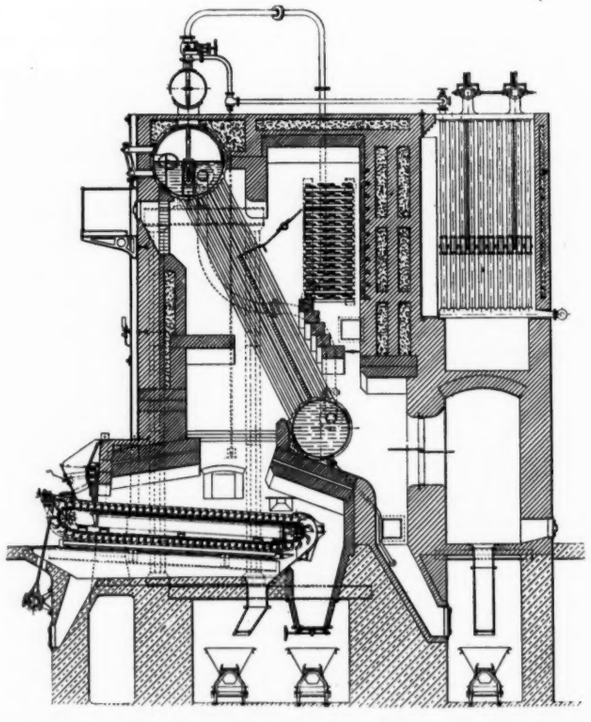

Fig. 1—The boilers installed at Porto Alegre are of this type but are fired by pulverized fuel equipment instead of stokers.

The plant has been designed for working with one turbo-alternator and three boilers, the two remaining units being for standby. For continuous

service it was necessary to provide the additional boilers, especially on account of the low-grade fuel and the frequent cleaning which is consequently involved.

The course taken by the coal is shown in the plan of the power plant in Fig. 1. From the receiving bunker the coal passes through the coal breaker. A hoist then delivers it to the conveying plant which distributes it into the bunkers above the boilers. At the outlet of the bunker each unit is provided with a coal weighing meter, integrating the coal consumption.

Contrary to the conditions stipulated by the suppliers of the plant, the coal fed into the mills contains 8 to 14 per cent moisture. Wear of the inner elements is therefore increased, as well as the power consumption; in addition, the large percentage of stone mixed with the coal occasions more wear especially as the stone is very hard. Its characteristics can be seen from the ash analysis below:

	1 per cent	2 per cent	Average per cent
Silicic anhydride ..... SiO_2	63.56	63.46	63.51
Titanic acid anhydride.... TiO_2	0.79	0.79	0.79
Sulphuric anhydride ..... SO_3	1.02	1.01	1.02
Phosphoric anhydride .... P_2O_5	0.03	...	0.03
Aluminum oxide ..... Al_2O_3	27.91	27.65	27.78
Iron oxide ..... Fe_2O_3	2.96	3.03	3.00
Calcium oxide ..... CaO	2.05	2.04	2.04
Magnesium oxide ..... MgO	0.46	0.45	0.46
	98.78	98.43	98.63

The coal is only slightly washed at the mine and the selecting by hand at the power plant depends largely on the workmen employed. According to the investigations made, the stone mixed with the coal has a specific gravity of 2.1 to 2.2, whereas the specific gravity of coal is about 1.3 to 1.4. The result is that the stone particles will not be carried away by the fan as readily as the actual coal. These stony particles remain in the mill and increase the wear and tear of the mill elements.

In spite of these difficulties, the combustion is perfect with the system employed. Repeated inspection of the combustion chamber and the various passes of the boilers have shown that the deposits are pure ash or pulverized stone. There is no trace of unburned particles or soot. Needless to say, the quantities of deposits are enormous, as the ash content represents more than one-third of the weight of fuel burned. The analyses of deposit samples from the combustion chamber, carried out by the afore-mentioned laboratory in Zürich, have confirmed this fact. The report gives 99.5 per cent ash, 0.1 per cent moisture and states that "the combustion is quite complete."

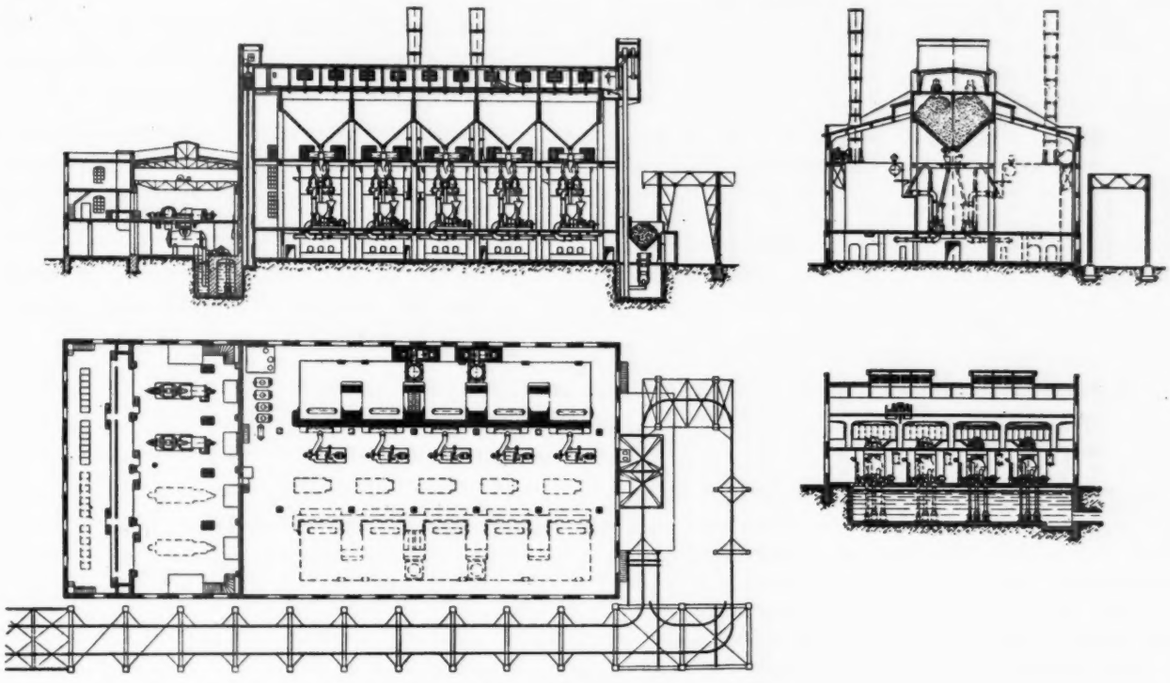

Fig. 2—Plan and elevations of power plant.

Owing to the water screen, the clinker does not cake in the lower part of the furnace and no troubles have been incurred in removing it. A part of the ash content is carried off through the chimney, and is visible as a white cloud. The effect can be noticed in the induced draft fans; blades and casings are subjected to wear and tear. Blades of reinforced construction have been provided from the beginning and interchangeable plates have been arranged in the casing for its protection. The induced draft installation is of the combined type; a part of the gas volume is drawn through the fan and forced into the chimney, carrying the rest of the gas with it by ejector effect.

The official trials were run two or three weeks after the plant had been put into operation, and without any cleaning of heating surfaces. The results gave the total average efficiency of the boiler,

(*Continued on page 33*)

Typical Gaseous Fuels*

By WM. L. DE BAUFRE

This is the fourth article in Mr. DeBaufre's group dealing with the subject of fuels and their combustion. In this article, the author discusses the various gaseous fuels, describing briefly their origin, general properties and use. Compositions and heating values are given in the accompanying tables, and curves are presented which show the air supplied for combustion and the products produced. These are so arranged as to permit of comparison with similar curves for solid and liquid fuels included in the author's article in August COMBUSTION. The latter part of the article shows combustion calculations for oil refinery gas, the method employed having been used in obtaining the data required for plotting the curves shown on Page 32.

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COMBUSTIBLE gas was first manufactured on a commercial scale somewhat more than one hundred years ago for the illumination of cities in England. The improvement over previous conditions was so great that the use of manufactured gas for this purpose soon spread to continental Europe and to America. The discovery some years later of large fields of natural gas in the United States resulted in natural gas being utilized in place of manufactured gas in nearby communities to which it could be readily piped. Natural gas is now conveyed hundreds of miles through pipe lines to communities at considerable distances from the gas fields.

Although the electric light has almost entirely displaced the gas light, the consumption of both natural and manufactured gas has steadily increased due to its use as a fuel in industry as well as in the home. In addition, large quantities of waste gases from certain industrial processes have come into use as fuels in those industries. Typical compositions and heating values will be given in this article for the more common fuel gases and curves showing the air supplied for combustion and the products produced will be included for comparison with those given in the August issue of COMBUSTION for typical solid and liquid fuels.

Natural Gas

Natural gas is found compressed in beds of sand or porous rock which lie under the earth's surface between close textured rocks that prevent the gas from escaping. It is obtained by wells drilled for the purpose or for securing petroleum with which natural gas is generally associated. When a new gas field is discovered, the gas is generally under a high "rock pressure"; but this pressure decreases as the gas is withdrawn until it becomes so low that the field must be abandoned.

Due to exhaustion of the Appalachian and other older gas fields, natural gas production has fallen off somewhat in recent years in New York, Pennsylvania, West Virginia, Kentucky, Ohio, Indiana, and Illinois. In the newer mid-continent gas fields of Kansas, Oklahoma, Texas, Arkansas, and Louisiana, however, production has greatly increased. This is also true of the western gas fields in Wyoming, Montana, and California.

Natural gas is generally stripped of its gasoline content and then consists chiefly of methane, ethane, and other saturated hydrocarbons together with small amounts of carbon dioxide and nitrogen. Appreciable amounts of hydrogen sulphide are sometimes present, but natural gas contains no carbon monoxide, hydrogen or illuminants and oxygen is present only when an infiltration of atmospheric air has occurred. The heating value of natural gas is usually around 1,000 B.t.u. per cu. ft. Occasionally, the percentage of carbon dioxide or of nitrogen is high with a corresponding reduction in the heating value of the gas. In exceptional cases, the gas consists almost entirely of these two inert gases and is valueless as a fuel.

Helium is obtained from certain natural gases containing one per cent or more of this element by liquefying all the other constituents at a temperature 200 degrees below zero centigrade.

The composition and heating value given in Table I may be taken for combustion purposes as typical of the natural gas from the mid-continent fields.

Manufactured Gas

Coal gas is manufactured by the partial destructive distillation of bituminous coal in an externally heated retort or chamber. The heating drives off volatile matter which is more or less broken down into fixed gas and carbon. Tar, light oil and ammonia may be recovered as by-products from

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the gas which is also usually purified of sulphur compounds. The coke residue in the retort or chamber amounts to about two-thirds of the coal processed.

Horizontal tube retorts were used for the production of coal gas in the early days of gas making. These were mounted in "benches" of six to nine retorts and heated by the combustion of gas produced from coke on grates in the lower part of the setting. City gas is today made for many communities, particularly in England, in the same form of apparatus. Inclined and vertical retorts have at times been employed in the larger gas plants to facilitate charging with coal and removing coke. In the largest city gas plants, however, coal gas is now made in by-product coke ovens which may be considered a development from the bee-hive coke ovens formerly used for producing metallurgical coke but from which the gas and other by-products were not recovered.

The coal gas produced in modern by-product coke ovens is similar in quality to that made in tube retorts. This quality depends upon the properties of the coal processed, the duration of the carbonizing period, the maximum temperature reached and somewhat upon the conditions of operation, such as the pressure or vacuum carried in the retort. Thus, when coal is carbonized at a low temperature, 1000 to 1400 fahr., the yield of gas is reduced and the yield of tar and light oil increased as compared with that obtained at the more usual carbonizing temperature of 1800 to 2100 fahr. At very high carbonizing temperatures, the volatile matter distilled from the coal is broken down to a greater extent than at the usual temperatures, thereby lowering the heating value of the gas discharged and increasing the accumulation of carbon on the walls of the retort.

In the early days of gas lighting, an illumination standard was set for city gas; but with the displacement of gas lights by electric lights and with the growth of the use of city gas for heating purposes, it has become customary to require a heating standard only. This standard is usually between 500 and 600 B.t.u. per cu. ft. of gas although a lower standard is sometimes permitted. In the International Critical Tables, typical compositions of coal gas are given for heating values from 450 to 700 B.t.u. per cu. ft. The composition corresponding to 550 B.t.u. per cu. ft. has been selected for inclusion in Table I.

Oil gas is made by cracking petroleum or one of its products in a retort heated internally or externally. If heated internally, the operation must be intermittent, as practiced for making city gas in California where oil is cheap relative to coal. If heated externally, the process may be continuous, as in the Pintsch system of gas making.

Pintsch gas is made in a double retort. The gas is formed by cracking oil in the first retort and the gaseous products are then passed through the second retort to fix them permanently by subjecting them to high temperature radiant heat from the walls of the retort. Pintsch gas is generally stored under a pressure of about twelve atmospheres and then utilized in tanks on buoys or in other isolated places. Pintsch gas was formerly much used for the illumination of railway coaches before the advent of the electric light.

To make city oil gas in California, a retort containing spaced checker brick is used. The checker bricks are first heated by burning oil in contact therewith. The air for combustion is then shut off and the oil sprayed onto the hot bricks. The oil is thereby cracked into gaseous products, tar, and lampblack. Steam is generally admitted to the retort for its influence upon the cracking of the oil and for combination with some of the lampblack to increase the yield of gas and reduce the amount of lampblack accumulating in the retort.

The data for oil gas in Table I are taken from the International Critical Tables where compositions are given for a range of heating values.

Water gas was first made suitable for city illumination about fifty years ago by Prof. Lowe, who developed apparatus for carburetting it with oil gas. Before being carburetted, the gas is known as blue water gas and has a low heating value and little illuminating power. It is sometimes used in the uncarburetted condition for industrial purposes.

Blue water gas is produced by the action of steam on incandescent coke or coal and consists principally of carbon monoxide and hydrogen as shown by the typical analysis in Table I. The addition of cracked oil vapors to bring the heating value up to 550 B.t.u. per cu. ft. results in a composition as tabulated for carburetted water gas.

The production of blue water gas is an intermittent process because the fuel bed cools down while being subjected to steam flowing through it. This is due to the principal reaction involved, namely, $H_2O + C = CO + H_2 - 70500$ B.t.u., being an endothermic reaction as indicated by the negative sign before the quantity of heat. As the fuel bed cools down, the quality of the gas decreases because another reaction, namely, $2H_2O + C = CO_2 + 2\,H_2 - 71800$ B.t.u., becomes relatively more important at lower temperatures. Also, the lower the temperature, the greater is the fraction of steam that passes through the fuel bed without being decomposed. The ratio of carbon monoxide to carbon dioxide and the portion of steam decomposed are also affected by the time of contact between steam and fuel, but the above effects of temperature changes are more noticeable.

Hence, it is necessary to interrupt the "run" of water gas making in order to raise the temperature of the fuel bed by blowing atmospheric air through it and thereby consuming a portion of the fuel in the exothermic reactions: $C + O_2 + 3.76\,N_2 = CO_2 + 3.76\,N_2 + 174{,}200$ B.t.u., and $C + \frac{1}{2}O_2 + 1.88\,N_2 = CO + 1.88\,N_2 + 52{,}500$ B.t.u. Both of these reactions occur simultaneously, their relative importance being determined by the temperature of the fuel bed and the time of contact between air and fuel. The longer the time of contact and the higher the temperature, the greater is the

ratio of carbon monoxide to carbon dioxide in the products of combustion. The gas made during the "blow" period is of such low quality by reason of the large percentages of carbon dioxide and nitrogen therein, that it is generally wasted.

Producer gas is made by blowing through an incandescent bed of coal or coke, atmospheric air

been commercialized by reason of the heretofore high cost of oxygen, no typical composition and heating value are given.

Waste Gases

Blast furnace gas is a by-product of the smelting of iron ore with coke, from 100,000 to 125,000 cu.

TABLE I.—COMPOSITION AND HEATING VALUE OF TYPICAL NATURAL, MANUFACTURED AND WASTE GASEOUS FUELS

	Natural gas	Coal gas	Oil gas	Carburetted water gas	Blue water gas	Producer gas	Blast furnace gas	Oil refinery gas
Reference No.	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8
Hydrogen sulphide (H_2S), per cent	.....	.....	.....	.....	.....	.....	.....	1.5
Illuminants, per cent	0	3.5	3.5	9.8	0	.....	.....	3.2
Carbon dioxide (CO_2), per cent	Trace	2.3	2.5	4.7	4.4	5.2	10.0	.....
Oxygen (O_2), per cent	0	0.6	.....	.....	.....	0.6	1.0	1.0
Carbon monoxide (CO), per cent	0	9.4	10.6	31.6	40.2	25.1	27.7	.....
Methane (CH_4), per cent	80.1	28.4	27.4	12.7	1.2	2.6	0.3	46.6
Ethane (C_2H_6), per cent	14.7	.....	.....	.....	.....	.....	.....	17.7
Propane (C_3H_8), per cent	.....	.....	.....	.....	.....	.....	.....	14.1
Butane (C_4H_{10}), per cent	.....	.....	.....	.....	.....	.....	.....	5.9
Hydrogen (H_2), per cent	0	49.3	50.3	37.5	50.5	14.0	3.0	6.0
Nitrogen (N_2), per cent	5.2	6.5	5.7	3.7	3.7	52.5	58.0	4.0
Density, lb. per cu. ft.	0.04944	0.03375	0.03341	0.04983	0.04093	0.06554	0.07571	0.06766
Specific gravity relative to air	0.650	0.444	0.439	0.655	0.538	0.862	0.996	0.890
Upper heating value under constant pressure, B.t.u. per cu. ft.	1050	550	550	550	300	150	100	1400
Lower heating value under constant pressure, B.t.u. per cu. ft.	950	493	493	505	274	141	98	1278
Upper heating value under constant pressure, B.t.u. per lb.	21240	16300	16460	11040	7330	2290	1320	20690
Lower heating value under constant pressure, B.t.u. per lb.	19220	14610	14760	10130	6690	2150	1296	18890

commingled with sufficient steam to balance by its endothermic reaction with the fuel the exothermic reaction of the oxygen with the fuel, thereby maintaining the temperature of the fuel bed constant. The steam also serves to cool the ash and thus reduce clinker troubles. Producer gas has a low heating value due to the large percentage of nitrogen introduced with atmospheric air. It is therefore not suitable for city purposes but is utilized in certain industrial heating operations and as a fuel for internal combustion engines. Its composition and heating value vary somewhat with the fuel used, anthracite coal, bituminous coal, or coke. The typical composition and heating value given in Table I correspond to bituminous coal.

Complete gasification of bituminous coal with recovery of by-products is now practiced by many large city gas companies by subjecting the coal first to partial destructive distillation in a coal gas plant and then utilizing the residual coke in a water gas plant. The purified coal and carburetted water gases are mixed for city purposes. It has been proposed from time to time to accomplish this complete gasification of coal in a single stage process in order to increase the thermal efficiency of gasification, reduce the initial investment and enable a lower grade fuel to be used than is now required to make a satisfactory coke. The simplest proposal is to make producer gas with nearly pure oxygen and steam rather than with atmospheric air and steam, thereby reducing the inert nitrogen in the gas to a small percentage. Such a gas would have double the heating value of ordinary producer gas. Since such a gasification process has not yet

ft. of gas being discharged from the top of the blast furnace per ton of pig iron produced. In the early days of the iron industry, this gas was wasted; but today it is practically all recovered and utilized as a fuel in furnaces and internal combustion engines in addition to preheating the air for the blast.

The quality of blast furnace gas is similar to that of producer gas by reason of the similarity of the two processes, both gases being produced by blowing atmospheric air through incandescent beds of carbon. The heating value of blast furnace gas, however, is less than that of producer gas by reason of the reduction of iron oxide in the shaft of the blast furnace by carbon monoxide formed in the hearth. Consequently, less carbon monoxide and more carbon dioxide are found in blast furnace gas than in producer gas. The ratio of carbon monoxide to carbon dioxide varies somewhat with the quantity of coke consumed per ton of pig iron produced. A typical composition and heating value are given in Table I.

Oil refinery gas is a by-product of the distillation of petroleum, being the fixed gas discharged from the top of the column when crude oil is separated into gasoline, kerosene, etc. Its composition varies widely by reason of differences in the characteristics of the crude oil refined and in the extent to which the oil has been subjected to cracking in order to insure the yield of gasoline. Its heating value is usually higher than that of natural gas due to the larger percentages of heavier hydrocarbons present. Also, illuminants, or unsaturated hydrocarbons, are generally present from the cracking operation. A typical analysis and

heating value for this gas are given in Table 1.

Simple Gases

Commercially available fuel gases are made up of a few simple gases as indicated by the compositions given in Table I. The combustible constituents are carbon monoxide, hydrogen and hydrocarbons, both saturated and unsaturated. Hydrogen sulphide is often present when the gases have not been purified.

The saturated hydrocarbons comprise methane, ethane, propane, butane, etc., but the conventional methods of fuel gas analysis do not show the proportions of all these constituents. The properties of the composite gas as a fuel, however, are practically the same for the percentages of methane and hydrogen, or of methane, ethane and hydrogen usually reported in analyses as for the actual percentages of all the saturated hydrocarbons present in the gas.

The unsaturated hydrocarbons comprise ethylene, propylene, butylene, pentylene, acetylene, benzol, and toluol, but the ordinary methods of gas analysis do not enable these to be separately determined. Their total percentage is found and usually designated as illuminants. The data in the International Critical Tables show that for coal gas and oil gas, the proportions of the various unsaturated hydrocarbons are such that the ultimate composition and heating value of the gas are closely approximated by assuming the illuminants to be propylene. While the correspondence is not so close for carburetted water gas, this assumption gives results closer to the actual values than if the illuminants were taken to be ethylene only, their chief constituent.

While all the simple combustible gases are commercially available in a nearly pure condition, it is economical to utilize them as fuels only under special conditions. Thus, propane and butane, separated from natural gas or refinery gas and compressed in cylinders, have recently come into use in isolated gas plants. Acetylene, prepared from calcium carbide by its reaction with water, is used for cutting and welding purposes by combustion with nearly pure oxygen, separated from atmospheric air by a liquefaction process. Nearly pure oxygen and nearly pure hydrogen are sometimes prepared by electrolytic separation of water. Hydrogen for industrial purposes is also prepared chemically by a number of different processes.

Although the simple combustible gases are seldom used in a nearly pure condition, their properties are of interest as indicating the characteristics of the composite commercial gases which are widely used as fuels. These properties will be more fully discussed in a future article on the thermodynamics of combustion reactions. For present purposes, Table II is given to show the moles of oxygen required for complete combustion, the moles of carbon dioxide and of water produced by complete combustion per mole of dry gas burned, and the upper and lower heating values per cubic foot of moisture-saturated gas at 60 fahr. under a total pressure of 30 inches of mercury, the standard conditions of the American Gas Association.

The mole ratios in Table II are taken from the tables in the article on "Combustion Heat Balance" in the June issue of COMBUSTION. The upper heating values are taken from the article on "Composition and Heating Value of Fuels" in the May issue, and are for combustion under constant pressure as explained therein. The lower heating values under constant pressure are calculated from the upper heating values by the method explained in that article.

Combustion Calculations

For any one of the typical gaseous fuels in Table I, a certain amount of oxygen is theoretically required for complete combustion. Usually, "excess air" over that containing the theoretically required

TABLE II.—SIMPLE COMBUSTIBLE GASES
Saturated with moisture at 60 deg. fahr. under 30 in. of mercury pressure

Gas	Chemical formula	O_2 required per mole of dry gas, moles	CO_2 formed per mole of dry gas, moles	H_2O formed per mole of dry gas, moles	Density of moisture saturated gas, lb. per cu. ft.	Specific gravity relative to air	Heating value of moisture saturated gas under constant pressure B.t.u. per cu. ft. Upper	Lower	B.t.u. per lb. Upper	Lower
Hydrogen	H_2	0.5	...	1.0	0.00606	0.080	319.5	270.4	52720	44620
Hydrogen sulphide	H_2S	1.5	1.0*	1.0	0.08932	1.175	619.0	569.9	6930	6380
Carbon monoxide.	CO	0.5	1.0	...	0.07354	0.967	316.0	316.0	4300	4300
Saturated hydrocarbons										
Methane	CH_4	2.0	1.0	2.0	0.04246	0.558	995	897	23440	21130
Ethane	C_2H_6	3.5	2.0	3.0	0.07885	1.037	1722	1575	21840	19970
Propane	C_3H_8	5.0	3.0	4.0	0.11525	1.516	2460	2264	21340	19640
Butane	C_4H_{10}	6.5	4.0	5.0	0.15164	1.994	3194	2949	21060	19450
Pentane	C_5H_{12}	8.0	5.0	6.0	0.18803	2.473	3918	3623	20840	19270
Illuminants										
Ethylene	C_2H_4	3.0	2.0	2.0	0.07362	0.968	1552	1454	21080	19750
Propylene	C_3H_6	4.5	3.0	3.0	0.11001	1.447	2322	2175	21110	19770
Butylene	C_4H_8	6.0	4.0	4.0	0.14641	1.925	3025	2829	20660	19320
Pentylene	C_5H_{10}	7.5	5.0	5.0	0.18280	2.404	3756	3511	20550	19210
Acetylene	C_2H_2	2.5	2.0	1.0	0.06838	0.899	1458	1409	21320	20610
Benzol	C_6H_6	7.5	6.0	3.0	0.20349	2.676	3680	3533	18080	17360
Toluol	C_7H_8	9.0	7.0	4.0	0.23989	3.155	4375	4179	18240	17420

* SO_2

quantity of oxygen, is actually supplied for combustion. Sometimes, there is a deficiency rather than an excess of air supplied for the combustion of gaseous fuels, but this condition will not be discussed in the present article which will be limited to the determination of the air supplied for combustion and the products produced with different percentages of excess air and complete combustion of the fuel gas. The method of calculation will be illustrated by Table III for oil refinery gas.

The moles of air supplied for combustion and the moles of products produced will be calculated per mole of dry gas burned. It will be assumed, however, that the gas burned is saturated with water vapor at 60 fahr. under a total pressure of 30 in. of mercury in accordance with the standards of the American Gas Association. Under these conditions, there is present in the gas as burned 0.0177 mole of water vapor per mole of dry gas. The atmospheric air supplied for combustion will be assumed to have 70 per cent relative humidity at 70 fahr., under which condition the air will contain 0.0176 mole of water vapor per mole of dry air.

In the first column of Table III are given the chemical symbols for the constituents of which the mole fractions based on dry gas are given in the second column. The third column contains the moles of oxygen per mole of dry fuel gas required for the combustible constituents in column two. The remaining columns contain the moles of products, classified as carbon dioxide, sulphur dioxide, nitrogen, oxygen, and moisture, per mole of dry gas in the moisture saturated gas burned.

The first item listed in the table is 0.018 mole of H_2O per mole of dry gas in moisture saturated gas at 60 fahr. under 30 inches of mercury. This item is also entered in the last column since there is no change in this moisture during combustion.

For the complete combustion of the sulphuretted hydrogen in the gas, $1.5 \times 0.015 = 0.023$ mole of O_2 is required and $1.0 \times 0.015 = 0.015$ mole of SO_2 and $1.0 \times 0.015 = 0.015$ mole of H_2O are formed per mole of dry gas, the mole ratios utilized being taken from Table II. By the use of similar mole ratios from Table II for the various hydrocarbons and for hydrogen, the O_2 required and the CO_2 and H_2O formed were calculated and entered in the appropriate columns of Table III. The mole fraction of O_2 in the fuel gas was entered in the third column and the mole fraction of N_2 was entered in the sixth column. The former was put in parentheses with a minus sign to indicate that it must be subtracted from the sum of the moles of oxygen required for all the combustible constituents of the gas in order to get the 2.816 moles of oxygen theoretically required for complete combustion of one mole of dry refinery gas.

With this 2.816 moles of oxygen will be associated in atmospheric air $2.816 \times 79/21 = 10.594$ moles of nitrogen, making $2.816 + 10.594 = 13.410$ moles of dry atmospheric air theoretically required for complete combustion of one mole of dry refinery gas. With this dry air will be associated $13.410 \times 0.0176 = 0.236$ mole of moisture, making $13.410 + 0.236 = 13.646$ moles of moist air theoretically required. These several quantities are entered in appropriate columns of Table III on the line marked "Theoretical air."

Adding the items in columns four to eight inclusive, we obtain for the complete combustion of refinery gas with the theoretical quantity of atmospheric air, the moles of each constituent in the products, namely, 1.567 moles of CO_2, 0.015 mole of SO_2, 10.634 moles of N_2 and 2.739 moles of H_2O per mole of dry gas in the moisture saturated gas burned. The apparent percentage of carbon dioxide in these products as would be found by analysis, is $(1.567 + 0.015) / (1.567 + 0.015 + 10.634) = 1.582/12.216 = 12.95$ per cent, which is the maximum possible carbon dioxide percentage with refinery gas.

With 15 per cent excess air actually supplied for combustion, the quantity of excess moist air is $13.646 \times 0.15 = 2.047$ moles, made up of $2.816 \times 0.15 = 0.423$ mole of O_2, $10.594 \times 0.15 = 1.589$ moles of N_2 and $0.236 \times 0.15 = 0.035$ mole of H_2O per mole of dry gas in the moisture saturated gas burned. These quantities are entered in appropriate columns in Table III. Adding these excesses to the theoretical quantities of air and of products for complete combustion, we get for 15 per cent

TABLE III.—COMBUSTION CALCULATIONS FOR OIL REFINERY GAS WITH 15 PER CENT EXCESS AIR

Symbol	Mole. fraction	O_2 required	——Products of combustion—— CO_2	SO_2	N_2	O_2	H_2O
H_2O	0.018	....	....	....	....	....	0.018
H_2S	0.015	0.023	....	0.015	....	....	0.015
C_2H_4	0.015	0.045	0.030	....	....	....	0.030
C_2H_6	0.010	0.045	0.030	....	....	....	0.030
C_3H_8	0.007	0.042	0.028	....	....	....	0.028
O_2	0.010	—(0.010)	....	....	....	....	....
CH_4	0.466	0.932	0.466	....	....	....	0.932
C_2H_6	0.177	0.620	0.354	....	....	....	0.531
C_3H_8	0.141	0.705	0.423	....	....	....	0.564
C_4H_{10}	0.059	0.384	0.236	....	....	....	0.295
H_2	0.060	0.030	....	....	....	....	0.060
N_2	0.040	....	....	....	0.040	....	....
Theoretical air	13.646	2.816	....	....	10.594	....	0.236
Theoretical products	.....	....	1.567	0.015	10.634	....	2.739
25 per cent excess air	2.047	....	....	....	1.589	0.423	0.035
Total air	15.693	....	1.567	0.015	12.223	0.423	2.774
Total products	....	....	....	....	17.002	....	....

of excess air: 15.693 moles of moist air actually supplied and 1.567 moles of CO_2, 0.015 mole of SO_2, 12.223 moles of N_2, 0.423 mole of O_2, and 2.774 moles of H_2O actually in the products of combustion per mole of dry gas in the moisture saturated gas burned. The apparent carbon dioxide percentage which would be found by analysis is $(1.567 + 0.015) / (1.567 + 0.015 + 12.223 + 0.423) = 1.582 / 14.228 = 11.12$ per cent for 15 per cent excess air.

The moles of air supplied and of products produced as calculated in Table III, may also be interpreted as approximately the cubic feet of air

supplied and of products produced per cubic foot of gas burned. But as the pressure and temperature of the air supplied and of the products produced may be different from that of the gas burned, it is preferable to calculate the volumetric ratios from the cubic feet of gas per mole under each temperature and pressure. Thus, in moisture saturated gas at 60 fahr. and under 30 inches of mercury total pressure, the standard conditions for gaseous fuels, the volume of one lb.-mole of dry gas is 385.1 cu. ft., see article on "Composition and Heating Value of Fuels" in the May issue of COMBUSTION. If the moist air supplied for combustion is at 70 fahr. under a total pressure of 29.92 inches of mercury, its volume is 386.8 cu. ft. per lb.-mole, as given in the article on "Thermal Properties of Gaseous Mixtures" in the February issue of COMBUSTION. From the same article, the volume of one lb.-mole of the moist products of combustion at say 500 fahr. under normal atmospheric pressure is 700.8 cu. ft. Hence, we have: 15.693 × 386.8 = 6070 cu. ft. volume of atmospheric air and 17.002 × 700.8 = 11915 cu. ft. volume of products of combustion per mole of dry gas in moist refinery gas burned with 15 per cent excess air. Also, 6070 / 385.1 = 15.76 cu. ft. of atmospheric air per cu. ft. of gas as burned and 11915 / 385.1 = 30.94 cu. ft. of products produced per cu. ft. of gas as burned.

The weights of air supplied and of products produced per unit weight of gas burned are calculated by aid of the molecular weights of the several constituents. Thus, for moist refinery gas, we have per mole of dry gas therein:

0.018 × 18.015	=	0.324 lb. of	H_2O,
0.015 × 34.080	=	0.511 " "	H_2S,
0.015 × 28.031	=	0.420 " "	C_2H_4,
0.010 × 42.046	=	0.420 " "	C_3H_6,
0.007 × 56.062	=	0.392 " "	C_4H_8,
0.010 × 32.000	=	0.320 " "	O_2,
0.466 × 16.031	=	7.470 " "	CH_4,
0.177 × 30.046	=	5.318 " "	C_2H_6,
0.141 × 44.062	=	6.213 " "	C_3H_8,
0.059 × 58.077	=	3.427 " "	C_4H_{10},
0.060 × 2.015	=	0.121 " "	H_2,
0.040 × 28.016	=	1.121 " "	N_2,

adding, we have 26.057 lb. of moist refinery gas per mole of dry gas therein. One mole of moist atmospheric air having 70 per cent relative humidity at 70 fahr. under normal atmospheric pressure, contains 1/1.0176 = 0.9827 mole of dry air and 0.0176/1.0176 = 0.0173 mole of moisture. Since the equivalent molecular weight of dry atmospheric air is 28.966 lb. as derived in the article on "Thermal Properties of Gaseous Mixtures" in the February issue of COMBUSTION, we have:

0.9827 × 28.966	=	28.465 lb. of	dry air, and
0.0173 × 18.015	=	0.312 lb. of	H_2O;

adding, we have 28.777 lb. per mole for the equivalent molecular weight of moist air.

Therefore,

15.693 × 28.777 = 451.6 lb. of moist air supplied per mole of dry gas in the moisture saturated gas burned. For the moist products of combustion, we have per mole of dry gas in the moist refinery gas burned:

1.567 × 44.000	=	68.9 lb. of	CO_2,
0.015 × 64.065	=	1.0 " "	SO_2,
12.223 × 28.16	=	344.2 " "	N_2 (atm.),
0.423 × 32.000	=	13.5 " "	O_2,
2.774 × 18.015	=	50.0 " "	H_2O,

making 477.6 lb. of moist products per mole of dry gas burned. Dividing above values, we obtain:

451.6 / 26.06 = 17.33 lb. of moist air supplied and 477.6 / 26.06 = 18.33 lb. of moist products produced per pound of moist refinery gas as burned with 15 per cent excess air.

The density of moisture saturated refinery gas at 60 fahr. under a total pressure of 30 inches of mercury, is found by dividing the weight of moist gas per mole of dry gas therein by the corresponding volume, or 26.057 / 385.1 = 0.06766 lb. per cu. ft. As the density of moisture saturated atmospheric air at the same temperature and pressure is 0.07604 lb. per cu. ft., see article on "Humidity of Gaseous Mixtures" in March issue of COMBUSTION, the specific gravity of moist refinery gas is 0.06766 / 0.07604 = 0.890 relative to air.

The density of the products of combustion at any temperature is equal to their weight divided by their volume at that temperature. At 500 fahr. under normal atmospheric pressure, for example, the density of the products of refinery gas burned with 15 per cent excess aid is 477.6 / 11915 = 0.04008 lb. per cu. ft.

The sensible heat in the air supplied for combustion at any desired degree of preheat and the sensible heat in the products of combustion at any specified temperature can readily be found by means of the table of sensible heats in the article on "Thermal Changes in Gases" in the September, 1930, issue of COMBUSTION. Thus, for the products with 15 per cent excess air at 500 fahr., we have:

1.582 × 4766.4	=	7540 B.t.u. for	CO_2 and SO_2,
12.646 × 3496.5	=	44216 B.t.u. for	N_2 and O_2,
2.774 × 4178.0	=	11590 B.t.u. for	H_2O,

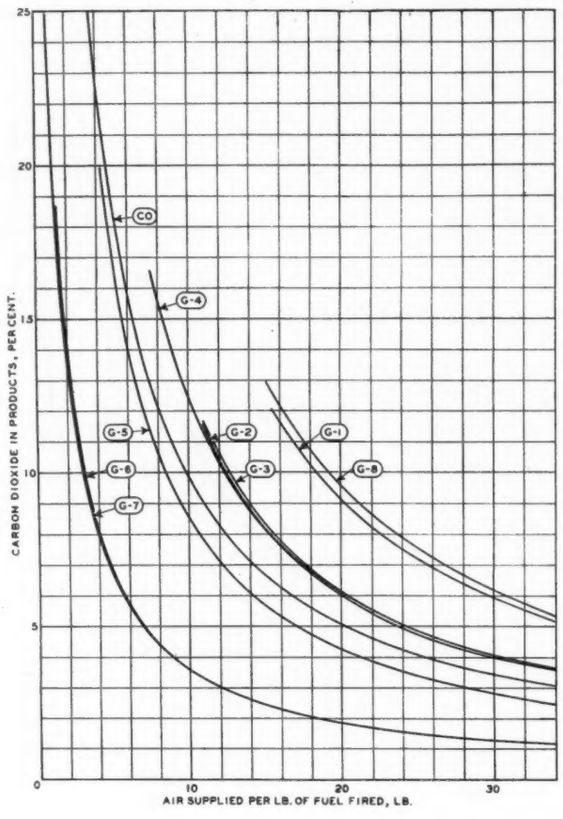
making 63346 B.t.u. for mole of dry gas in the moist gas burned. For 70 fahr., we have:

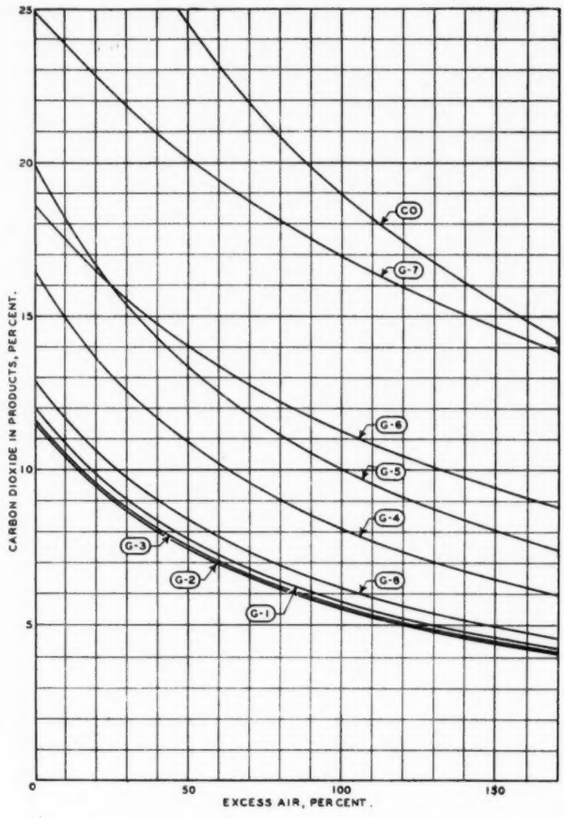
1.582 × 613.3	=	970 B.t.u. for	CO_2 and SO_2,
12.646 × 487.2	=	6161 B.t.u. for	N_2 and O_2,
2.774 × 580.8	=	1611 B.t.u. for	H_2O,

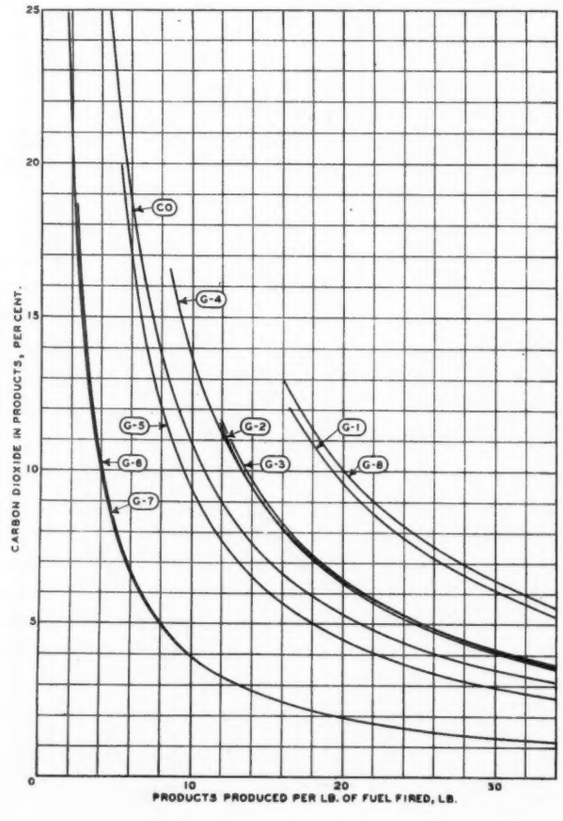
making 8742 B.t.u. per mole of dry gas in the moist gas burned. Hence, 63346 — 8742 = 54604 B.t.u. sensible heat above 70 fahr. in the products of combustion per mole of dry gas in the moist gas burned. The sensible heat may be reduced to one cubic foot of the fuel gas as burned by dividing by 385.1 cu. ft. per mole under standard fuel gas conditions, or the sensible heat may be reduced to one pound of the products by dividing by the corresponding weight of the products, namely, 477.6 lb. By dividing by 26.057 lb. of moist refinery gas per mole of dry gas therein, we obtain the sensible heat in the products per pound

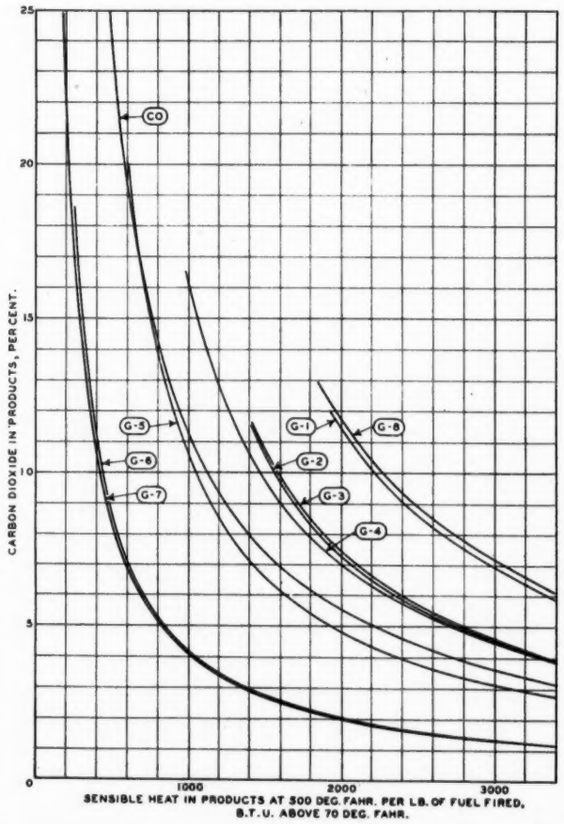
TYPICAL GASEOUS FUELS

Curve numbers correspond with reference numbers in Table I









of fuel as burned; thus, 54604 / 26.057 = 2095.6 B.t.u. sensible heat in the products above 70 fahr. per lb. of fuel fired.

The specific heat of the products of combustion is calculated by aid of the table of specific heats in the article on "The Thermal Properties of Gases" in the July 1930 issue, of COMBUSTION. At 500 fahr., we have:

1.582 ×	10.36 =	16.39 B.t.u. for	CO_2 and SO_2,
12.646 ×	7.04 =	89.03 B.t.u. for	N_2 and O_2,
2.774 ×	8.46 =	23.47 B.t.u. for	H_2O,

making 128.89 B.t.u. per mole of dry gas in moist refinery gas. Since there are 477.6 lb. of products per mole of dry gas in the moist refinery gas burned with 15 per cent excess air, the specific heat of these products at 500 fahr. is: 128.89 / 477.6 = 0.270 B.t.u. per deg. fahr. per lb. of products.

Products of Typical Fuels

Applying to all the typical gaseous fuels listed in Table I, similar combustion calculations to those just described for refinery gas, data were obtained for plotting the curves on page 32. It may be mentioned that in all cases complete combustion of the fuel gas was assumed. The various curves are numbered in accordance with the reference numbers in Table I. Curves for carbon monoxide, designated by CO, have been drawn for comparison.

The curves for typical gaseous fuels in the present article may be compared with similar curves for typical solid fuels and for typical liquid fuels in the article on this subject in the August issue of COMBUSTION.

References

Volume II of the International Critical Tables contains data on the properties of gaseous fuels, giving for coal and coke-oven gas, for carburetted water gas, for oil gas, and for producer gas, series of corresponding compositions and heating values.

Numerous U. S. Bureau of Mines publications deal with gaseous fuels, among which may be mentioned Technical Paper 120 entitled "A Bibliography of the Chemistry of Gas Manufacture" and Bulletin 301 on "Facts Relating to the Production and Substitution of Manufactured Gas for Natural Gas."

For a modern book on gas making, see Manufactured Gas, A Textbook of American Practice, by J. J. Morgan. The handbooks published by the American Gas Association may also be consulted.

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General Refractories Company announces that Harry S. Schleicher has become associated with its sales organization, with headquarters in the company's New York office. Mr. Schleicher was formerly vice president of the North American Refractories Company.

New Brazil Plant Burns Low-Grade Coal at High Efficiency

(*Continued from page 25*)

including superheater and economizer, as 80 per cent with an evaporation of 6.15 lb. per sq. ft. of heating surface, i.e., 21,000 lb. of steam per hour per boiler. This efficiency is based on a calorific value of 7750 B.t.u. These tests were carried out on 3 boilers, the load on the turbine being 5850 kw. At maximum load of the turbine, that is, 6250 kw., each boiler was producing 23,800 lb. per hour. The efficiency at normal load corresponds to an evaporation of 5 lb. of water per lb. of coal. In the guarantees given, the efficiency had been fixed at 70 per cent owing to the low grade of coal and the variations expected. Further the fuel had been specified with a calorific value of 8100 B.t.u. and with 30 per cent ash and 5 per cent moisture. In spite of the unfavorable differences in the characteristics of the coal the efficiency obtained is much above the guarantee.

The excessive wear of the inner elements of the mills has been mentioned previously. In connection with this, it may be of interest to compare the cost of maintaining them and the additional expenses incurred with the gain obtained on account of the high efficiency.

The calculations are based on the following figures:

Maximum calorific value, 7,200 B.t.u.

Daily coal consumption (San Jeronymo coal), 100 tons.

Fuel price, delivered on site, per ton $5.07.

The annual fuel consumption amounts to 365 x 100 = 36,500 tons, and the corresponding costs are: 36,500 x $5.07 = $185,014.83.

The cost of preparing the coal consists of maintenance of the mills, beaters and other elements subjected to wear and tear per ton of coal.....	18.6 cents
Electric power per ton of coal	30.2 "
Amortization of the mills per ton of coal	15.6 "
Total per ton	64.4 cents

The rate of amortization has been taken at 25 per cent since the machines are subject to such great wear and tear. The figure of 64.4 cents per ton of coal corresponds to an annual expense of 64.4 x 100 x 365 = $23,506.00.

The total expenditure for coal and for maintenance of the mills amounts to $208,561.00.

On the other hand, the same boiler plant working with a 70 per cent efficiency (according to the guarantee given) would have an annual coal bill of $\frac{80}{70}$ x 38,020 = $211,491.00.

This figure surpasses even the former one, which contains all additional cost for maintenance, electric power and amortization. It must be consid-

(*Continued on page 36*)

The Value of Clean Coal for Steam Generation*

By EDWIN B. RICKETTS
Research Engineer
New York Edison Company, New York

The author presents formulas for calculating the effect of variation in ash content on steam cost and includes examples showing the practical application of these formulas. The two formulas given show values relative to 5 per cent ash coal as a base; one covers conditions where excess capacity is available and investment factors need not be considered, the other assuming the opposite conditions.

COAL has many characteristics the variations in which materially affect its value for use on most types of combustion equipment. The scope of this paper is, however, confined to the effect of variations in the ash content of coal on its value for steam generation.

The development of the art today offers combustion equipment capable of providing the necessary capacity, together with good efficiency, when supplied with almost anything in the way of fuel from the best grades of coal having an ash content of 4 to 5 per cent to a black real estate containing 40 to 50 per cent ash. Thus, if the type of fuel to be used is definitely known in advance of design, suitable equipment can be provided, at a cost, for its combustion.

The development of the art of cleaning coal has reached a point where, by the use of suitable methods, there can be manufactured, at a cost, from high ash coals a product suitable for use on combustion equipment designed for high grade fuel.

If our problem were the simultaneous development of a steam plant and a low grade coal field to supply that steam plant, both properties being under common ownership, we would have a simple case of balancing the cost of coal cleaning against that of burning the high ash coal, but such a situation is very much the exception.

The cheapest coal to use in any given plant is that coal which, considering fixed and operating charges, will produce the most heat units in the steam for a dollar.

The factors in the cost of steam production that are influenced by the ash content of coal are as follows:

1. Capacity available
2. Cost of coal per million B.t.u. in bunkers
3. Boiler plant efficiency
4. Cost of operating labor and maintenance per million B.t.u. in steam
5. Cost of ash handling and disposal per million B.t.u. in steam

While the fundamental formulas involved in a determination of the effect of variations in ash content on the cost of steam generation are of universal application, the constants involved vary through quite wide limits due to differences in fuel burning equipment and in the cost of labor and materials.

Below are given the formulas for calculating the effect of variations in ash content on the cost of steam generation, together with a number of examples of their practical application. While the constants used in these examples are the average of those experimentally determined for three large boiler plants they should be considered as illustrative only and before the solution of a specific problem is undertaken the value of the constants applicable to the plants under consideration must be determined.

Formulas for Calculating the Effect of Variations in Ash Content on the Value of Coal to the Consumer

Assumptions:

1. The maximum steam demand on the plant is equivalent to 100,000,000 B.t.u. in steam per hour.
2. The plant under consideration has a capacity of 100,000,000 B.t.u. in steam per hour when supplied with 5 per cent ash coal.
3. The cost of the boiler plant complete is $300,000.00 and additional capacity can be purchased for $3.00 per 1000 B.t.u. per hour in steam.
4. Fixed charges at 12.5 per cent per year or $4.28 per hour on the plant of 100,000,000 B.t.u. capacity in steam per hour.

Let X = Cost in dollars per net ton of

* Presented at the Third International Conference on Bituminous Coal, Pittsburgh, Nov. 16-20, 1931.

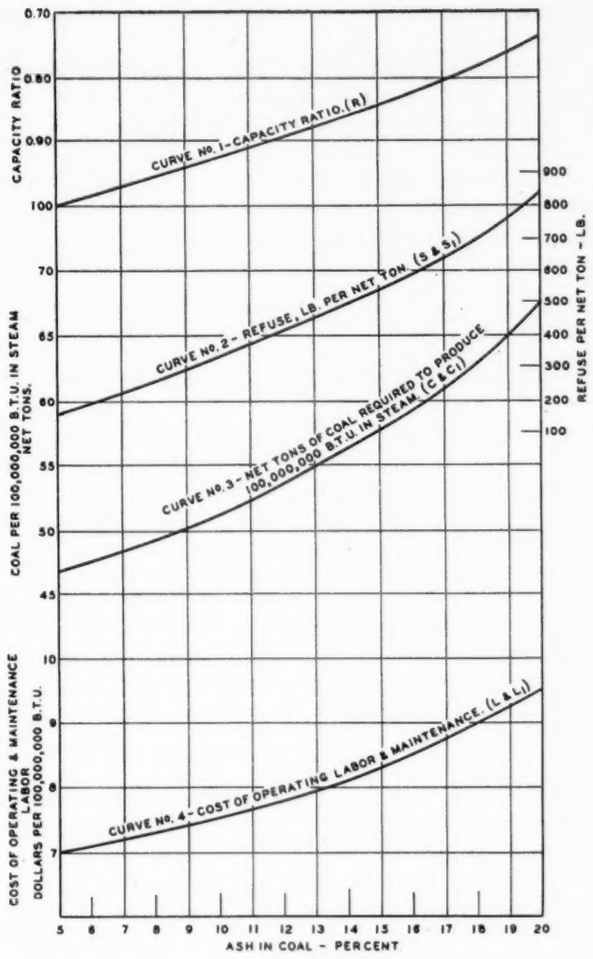
CAPACITY RATIO
CURVE NO. 1 - CAPACITY RATIO. (R)
CURVE NO. 2 - REFUSE, LB. PER NET TON. (S & S1)
CURVE NO. 3 - NET TONS OF COAL REQUIRED TO PRODUCE 100,000,000 B.T.U. IN STEAM. (C & C1)
CURVE NO. 4 - COST OF OPERATING LABOR & MAINTENANCE. (L & L1)
COAL PER 100,000,000 B.T.U. IN STEAM NET TONS.
COST OF OPERATING & MAINTENANCE LABOR DOLLARS PER 100,000,000 B.T.U.
REFUSE PER NET TON - LB.
ASH IN COAL - PERCENT

Fig. 1—Relation of cost factors to percentage of ash in coal.

5 per cent ash coal in bunkers

Y = Value in dollars per net ton of x per cent ash coal in bunkers

Z = Total cost of 100,000,000 B.t.u. in steam with 5 per cent ash coal.

Also Z = Total cost of 100,000,000 B.t.u. in steam with x per cent ash coal if this coal costs Y dollars per ton

C = Net tons of 5 per cent ash coal required to produce 100,000,000 B.t.u. in steam

C_1 = Net tons of x per cent ash coal required to produce 100,000,000 B.t.u. in steam

S = Pounds of refuse per net ton from 5 per cent ash coal

S_1 = Pounds of refuse per net ton from x per cent ash coal

U = Cost of ash handling and removal in dollars per pound

L = Cost in dollars of labor and maintenance to produce 100,000,000 B.t.u. in steam with 5 per cent ash coal

L_1 = Cost in dollars of labor and maintenance to produce 100,000,000 B.t.u. in steam with x per cent ash coal

A = Capacity factor

$$= \frac{\text{B.t.u. absorbed by steam per year}}{\text{Maximum capacity in B.t.u. absorbed, per hour} \times 8760}$$

B = Fixed charges per hour on cost of boiler plant. Assumed = \$4.28

R = Capacity ratio

$$= \frac{\text{Maximum capacity of boiler plant with x per cent ash coal}}{\text{Maximum capacity of boiler plant with coal used as a base}}$$

Formulas:

Value relative to 5 per cent ash coal as a base

1. ***Where excess boiler capacity is available and investment factors need not be considered***

$$Z = CX + CSU + L = C_1Y + C_1S_1U + L_1$$

$$C_1Y = CX + CSU + L - C_1S_1U - L_1$$

$$(1) \qquad Y = \frac{CX + CSU + L - C_1S_1U - L_1}{C_1}$$

2. ***Where excess boiler capacity is not available and investment factors must be considered***

$$Z = CX + CSU + L + \frac{B}{A} = C_1Y + C_1S_1U + L_1 + \frac{B}{AR}$$

$$C_1Y = CX + CSU + L + \frac{B}{A} - C_1S_1U - L_1 - \frac{B}{AR}$$

$$(2) \quad Y = \frac{CX + CSU + L + \frac{B}{A} - C_1S_1U - L_1 - \frac{B}{AR}}{C_1}$$

Example 1. Investment factors not included

When 5 per cent ash coal costs \$4.00 per net ton in bunkers and ash handling and removal costs \$0.20 per ton, find the value of 18 per cent ash coal. We have:

C = 4.67 (from curve No. 3) C_1 = 6.28 (from curve No. 3)
X = \$4.00 S_1 = 695 (from curve No. 2)
S = 160 (from curve No. 2) L_1 = \$9.00 (from curve No. 4)
U = \$0.0001
L = \$7.00 (from curve No. 4)

Substituting in equation (1)

$$Y = \frac{18.68 + 0.0747 + 7 - 0.4364 - 9}{6.28} = \$2.60$$

Example 2. Investment factors included

When 5 per cent ash coal costs \$4.00 per net ton in the bunkers, ash handling and removal costs \$0.20 per ton, capacity factor is 0.50. Find the value of 18 per cent ash coal. We have:

C = 4.67 (from curve No. 3) C_1 = 6.28 (from curve No. 3)
X = \$4.00 S_1 = 695 (from curve No. 2)
S = 160 (from curve No. 2) L_1 = \$9.00 (from curve No. 4)
U = \$0.0001 A = 0.5
L = \$7.00 (from curve No. 4) B = \$4.28
A = 0.5 R = 0.78 (from curve No. 1)

Substituting in equation (2)

$$Y = \frac{18.68 + 0.0747 + 7 + \frac{4.28}{0.5} - 0.4364 - 9 - \frac{4.28}{0.39}}{6.28} = \$2.22$$

It will be noted from Example 2 that, for the particular plant under consideration, an increase of 13 per cent in ash reduces the value of the high ash coal by nearly 50 per cent. Obviously under ordinary circumstances this low grade coal cannot be supplied to this type of plant at a mutually profitable price.

A coal operator confronted with such a situation will, having in mind the cost of cleaning his product, consider the relative advantages of manufacturing from his raw material a more suitable product, or seeking a market where the combustion equipment is better suited to his coal.

The problem of the mutual adaptation of coal and combustion equipment has been faced many thousands of times, in some cases it has been solved by the better cleaning of the coal, in others by changes in the combustion equipment or, in both coal cleaning and combustion equipment. In a relatively small number of cases the decision has been based on an exhaustive analysis of the engineering and economic factors involved, but in the vast majority the foundation for the decision has been little more than a hunch.

This paper is offered in the hope that the solution of the example presented, will emphasize the necessity for the mutual interest of coal producer and consumer in the scientific determination of the factors governing the economics of both the cleaning and the combustion of coal to the end that that combination of cleaning and combustion equipment be selected which will produce the greatest amount of steam for a dollar.

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New Brazil Plant Burns Low-Grade Coal at High Efficiency

(*Continued from page 33*)

ered that for establishing a comparison, the costs due to normal wear, power consumption and amortization would have to be added to the amount of $211,491.00.

According to Munzinger (Dampfkesselwesen in den Vereinigten Staaten 1925 and other data in the serial reports of the Prime Movers Committee, New York) the expenses for the mills established as above and for a normal fuel reach about 71 cents per ton.

The figure for the plant in Porto Alegre is below this in spite of the bad quality of the coal and the lack of drying plant, which latter had been foreseen and would have reduced the power consumption of the mill and the wear of its elements. The Holtwood Station of the Pennsylvania Water and Power Co. mentions a figure of 62.2 cents per ton of pulverized coal for the total expenses occasioned by the mills.

When using British coal, the annual expenses for fuel would be as follows:

Calorific value admitted 13,700 B.t.u.

Coal price per ton delivered on site $14.43.

Admitting a higher efficiency than with Brazilian coal, say 84 per cent instead of 80 per cent and with the respective calorific values of 7200 and 13,700 B.t.u. per lb., the annual coal consumption would be $\frac{7200}{13700} \times \frac{80}{84} \times 36{,}500 = 18{,}500$ tons and the annual costs, excluding mill expenses, 18,500 x $14.43 = $266,955.00.

This amount exceeds, by approximately 25 per cent the figure of $208,561.00 representing the total expenses for fuel and mill maintenance when using San Jeronymo coal. Even when the cost of handling the large quantities of ash contained in the Brazilian coal is taken into consideration the difference between the cost of both fuels is still enormous in the present case.

Before concluding a few examples of other means adopted in some boiler plants using this particular coal shall be mentioned. In several plants, stoked by hand, a mixture of this coal and eucalyptus wood is burned the latter in pieces about 3¼ ft. long. In a modern installation equipped with chain-grate stokers, the operating engineers have found out from the different tests performed with this coal that the best possible results are obtained by adding 130 Imperial gal. of water to each ton of coal, that means about 60 per cent of the fuel weight. Otherwise, the combustion was worse, and the removal of the strongly caking clinker occasioned much work. These troubles were so great, that it pays to work the plant in the above-mentioned manner, in spite of the 11 or 12 per cent loss of efficiency caused by evaporating this additional water.

The writer is indebted to Messrs. Sulzer Bros. for the above details and the diagrams.

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Boiler Feed Water Investigations

Two experimental programs have recently been started at the Ohio State University and at the University of Michigan by the joint Research Committee on Boiler Feedwater Studies. This Committee is sponsored by the American Boiler Manufacturers' Association, the American Railway Engineering Association, the American Society for Testing Materials, the American Water Works Association, the National Electric Light Association and the American Society of Mechanical Engineers. The work at Ohio State, which will investigate priming and foaming characteristics of boiler waters, is in charge of Prof. C. W. Foulk, while that at the University of Michigan will pertain to various methods of water analysis and will be under the direction of Prof. A. H. White.

The Plant Storeroom

By O. O. ZAPPE

Plant Engineer,

Southwestern Public Service Co.,

Amarillo, Texas

A properly operated plant storeroom implies a readily accessible supply of repair parts and other stock items with a record system that assures an adequate supply of all articles at all times without unnecessarily heavy inventories. The author describes the routine of storeroom operation and a simple record system which assures replenishment of stock at the necessary intervals.

THE proper care of the storeroom in the plant is a problem that confronts every plant engineer. Not only should it be a place for merely storing articles, but it should also be a place where they are continuously replenished, easily and quickly located and records of shipments and supplies on hand recorded for the information of all concerned.

A simple and practical system which can be used for plants both large and small and which requires a minimum of time and energy is outlined. In the case of the average plant a few minutes a day is all that is required.

First, a storeroom should, if possible, be a room devoted solely to this purpose. If a separate room cannot be set aside then a certain portion of space free from congestion and cleared of all other equipment should be provided. If more than one storeroom is required, say on different floors, or if special cabinets containing certain supplies necessary only in one particular part of the building are used to supplement the storeroom, this can also be incorporated under the same system.

The storeroom proper should, of course, contain sufficient shelving and compartments to allow all parts and supplies to be placed so that they will not only be easily accessible, but to also allow for quick inspection. Parts or supplies which are of such nature as to require closed cabinets due to their being damaged by dust, etc., or because of their high cost, should be provided for.

Second, the responsibility for the care of the storeroom, or storerooms and special cabinets, should be placed on one person only. If the plant is a large one the additional storing and issuing of tools used throughout the plant usually becomes a part of his work and an assistant may be necessary. However, whether the plant be large or small, unless this is adhered to, confusion and dissatisfaction will result.

Finally, all deliveries of shipments regardless of where they are to be used, should be delivered first to the storeroom where they can be checked and listed on the records.

A Tickler Card File

To enter the necessary information and to provide a continuous record and inventory for all supplies carried, a tickler card file may be used. A typical card for such a file is shown in Fig. 1. As shown on the card all the required information covering any item can be had at a glance.

The cards are filed in alphabetical order with markers labeled according to subject for classifying the different groups of items. These markers are inserted in staggered position on the left side of the file. On the right side, markers numbered consecutively from one to thirty are placed and divide the cards into equal groups irrespective of their subjects. However, it is preferable to have these markers coincide, where possible, with the subject marker, so that items of a certain subject group will fall into only one number group.

Subject markers can be expanded so as to enable quick location of any item wherever there are a considerable number of cards under that subject. For instance, under "Fittings, High Pressure," smaller markers labeled ⅛ in., ¼ in., ⅜ in., etc., should be inserted. Similarly, subdivision markers should be placed under other subjects covering a large number of items. Such a file is shown in Fig. 2.

Operation

Once the supplies are properly placed on the shelving or "pigeon-holed" according to a suitable arrangement which will present a neat and accessible appearance, operation of the system should begin. Items which are hard to identify or not commonly known, should be tagged and all shelving and compartments should be labeled or stenciled according to items contained.

It will be noted that on the card the notation "Index No." appears. This is used only where it is desirable to locate the item by number, the particular location bearing the same number as that on the card or where certain supplies are kept in

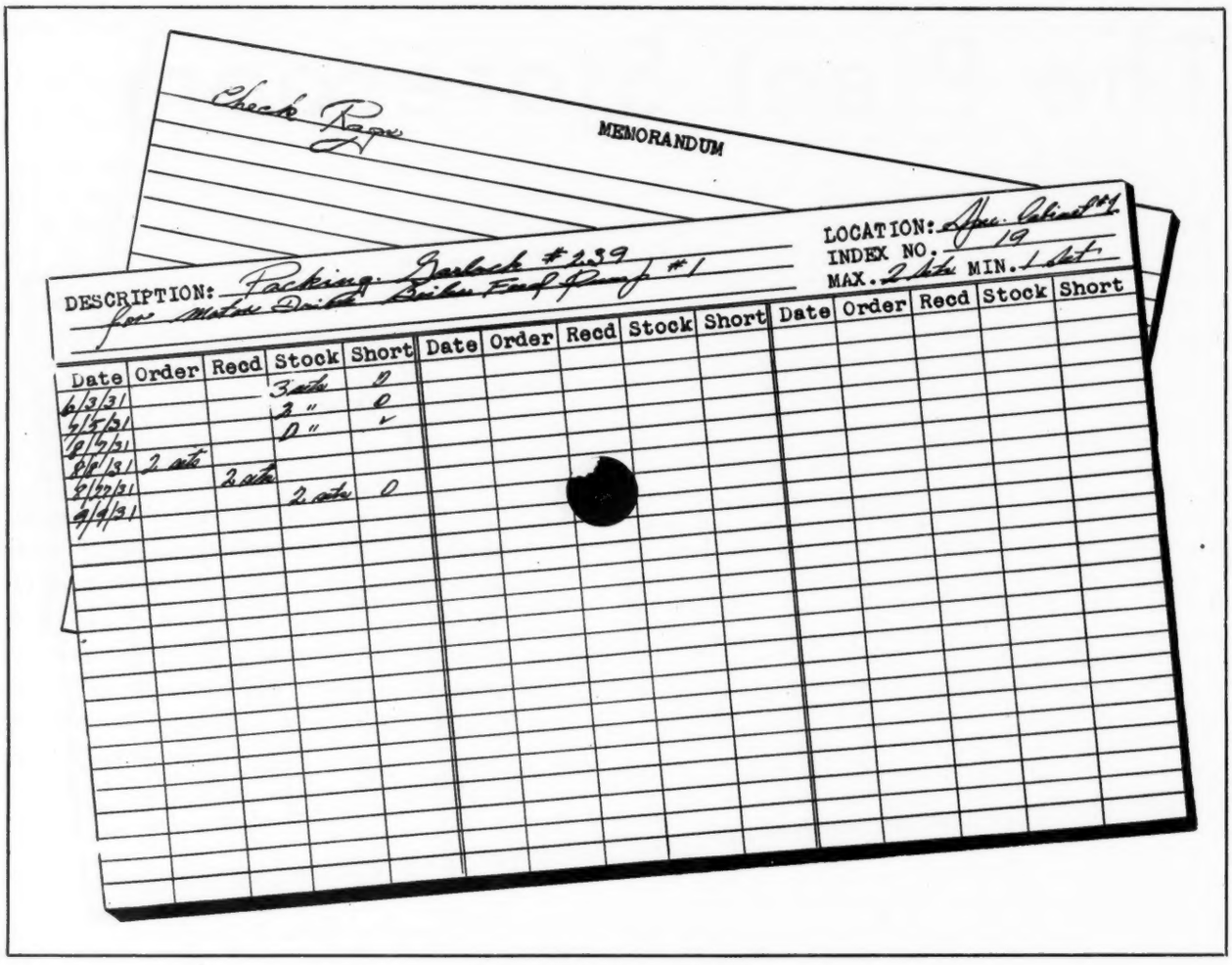
Check Rags
MEMORANDUM
DESCRIPTION: Packing Garlock #239 for Motor Driven Boiler Feed Pump #1
LOCATION: Upper Cabinet #1
INDEX NO. 19
MAX. 2 Sets MIN. 1 Set
Date Order Recd Stock Short
Date Order Recd Stock Short
Date Order Recd Stock Short

Fig. 1—Card used in tickler file.

small boxes either on a shelf or in a cabinet and quick identification of the individual sizes or items is otherwise difficult. Packing is such an item and the index number can either be marked on the box with a colored pencil or on a gummed label provided for the purpose.

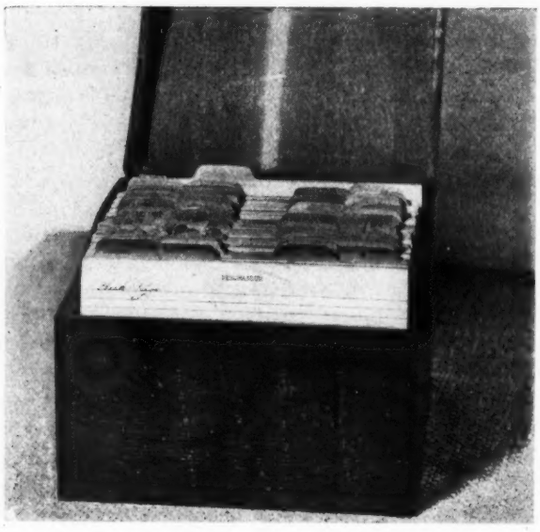

Fig. 2—Ticker card file.

Under "Description," the full description together with ordering directions should be entered. "Max" and "Min" indicate the maximum and minimum amounts that are desired to be carried. These amounts must be arrived at through experience since it is difficult to determine in many instances just what amounts should be carried. To begin, it is a good idea to estimate the amount of the particular item that will be required per month and enter this figure under "Minimum." The "Maximum" figure will also depend, of course, upon the particular item, cost and other factors which necessitate its being carried in stock.

As may be surmised from the foregoing, the system is based on a thirty-day interval period. In other words, each day a new group of cards are considered and in this manner a perpetual check of all supplies is obtained. Items which need a more frequent check than every thirty days such as lavatory supplies, rags, etc., are taken care of by special tickler cards, (Fig. 1) calling the attendant's attention to the original card covering this item, which card alone contains all the information on the item and maintains its respective place in the file.

To start the system, the cards in the group cov-

(*Continued on page 51*)

An Entirely New Type of Prime Mover

Remarkable Claims Made by a British Inventor, for an Engine Operated Entirely by the Expansive Force of a Liquid

By DAVID BROWNLIE, London

While there is undoubtedly room for a difference of opinion as to the feasibility of the new type of engine described in this article there can be no question but that its principle of operation is a matter of definite interest. This principle is based on the expansive properties of liquids in the higher temperature ranges and apparently has been successfully applied in the Malone engine. At any rate the inventor was given a hearing before the Royal Society of Arts in London on June 4, 1931, when he presented a paper which was received with marked interest.

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FOR more than 1000 years, the human race has been struggling to develop economical methods of power generation, in the course of which there has been evolved the water wheel and eventually the water turbine using the energy in falling water, the windmill, making use of the power in the wind, and the steam engine, with the expansive force of steam employed in driving a piston or a turbine wheel. We also have the internal combustion engine in its multitudinous forms, using gaseous, liquid, or solid fuel and more recently we have witnessed the use in boilers of new heat transfer mediums such as mercury and diphenyloxide. Various entirely unorthodox methods of power generation have been conceived and practiced such as the tapping of volcanic areas for natural steam, as in Italy and the remarkable attempts of Georges Claude and his associates to utilize the difference in temperature between the relatively warm top layer of the oceans and the vast bulk of extremely cold water beneath for driving turbines. Experiments have also been made in the use of the heat of the sun direct, or the energy of molten lava beneath the earth by means of tubes going down a mile or so, the latter having been one of the pet schemes of the late Sir Charles Parsons.

Now there has been evolved by a British inventor, J. F. J. Malone, of Newcastle, an entirely new method of driving an engine, that is the use of the expansion of liquid instead of gas for operating a piston, the first engine on these lines having been built in 1925. It is now more or less well known, stimulated by the result of the work of Benson and other pioneers in the use of super-steam pressures up to 3200 lb. per sq. in., that water, shortly before the "critical" condition of 3200 lb. per sq. in. pressure and 706 deg. fahr. possesses abnormal properties of expansion. That is from say 32 deg. fahr. (freezing point) to about 500 deg. fahr. the rate of expansion is more or less regular and in proportion to the temperature, but after this point the rate of expansion becomes greater as the temperature increases until approximately 690 deg. fahr. is reached, when an entirely abnormal period commences and the expansion is out of all proportion to the rise in temperature, although of course the water is still in the purely liquid condition.

The position is well illustrated by the following figures for the density of water at various typical temperatures and pressures up to the critical conditions.

Temperature of water, deg. fahr.	Pressure, lb. per sq. in. absolute	Density of water, lb. per cu. ft.
32	0.089	62.4
100	0.950	62.0
200	11.52	60.1
212	14.70	59.9
300	67	57.3
400	247	53.5
500	679	48.7
600	1540	41.8
690	2883	32.1
706	3200 (critical)	20.1

Thus from 32 deg. fahr. to 500 deg. fahr. water gradually expands from a density of 62.4 lb. per cu. ft. to 48.7 lb. After 500 deg. fahr., however, the rate of expansion increases much more in proportion to unit temperature rise and at 690 deg. fahr. for example is only 32.1 lb. per cu. ft. as compared with 48.7 lb. at 500 deg. fahr. Beyond 690 deg. fahr. the conditions become more erratic so that a

rise of only 16 deg. fahr. from 690 deg. fahr. to 706 deg. fahr. results in an increase of volume of 60 per cent, which is much more than the increase represented by a rise from 32 deg. fahr. to 600 deg. fahr., that is 568 deg. fahr.

In view of these circumstances there is the possibility of driving an engine piston by heating water already at say 400 deg. fahr. to 700 deg. fahr. under high pressures so that the enormous expansion, that is change of pressure, is utilized without the necessity of converting to steam, the water being then discharged from the piston in a closed circuit and reheated again to 700 deg. fahr.

Of course, almost any liquid might, on theoretical grounds, be used for the purpose instead of water, since more or less all liquids show the same phenomenon of gradual increase in volume with rise in temperature until the critical conditions begin to be approached when the rate of the volume increase becomes much higher than the normal. However, under these conditions of high pressures and rapid heat transfer water is found by experience to be the best, although mercury is also very good, and was used in the original small experimental plant constructed by the inventor.

Essentially the "Malone" engine is an arrangement whereby water or other liquid is used on these lines always under high pressures of a number of tons per sq. in. in a closed circuit, heated at one end to about 900 deg. fahr. and cooled to say 70 deg. fahr. by cold water or air at the other. The water under these conditions expands rapidly, drives a piston, is cooled, and returns to the heated end again while both the very rapid heating and cooling necessary are carried out with the water in the condition of an extremely thin film, not over 0.01 in.

One of the main contentions of the inventor is that when liquids are made to move correctly in thin films, within metal walls, an exceedingly high rate of heat transmission efficiency is obtained, and in fact he maintains that heat transfer of this kind can heat and cool liquids as quickly as the periodicity of alternating electricity, and with less loss than occurs in large modern static transformers. Also a primary feature is that the dilatation of liquids is greater than their compressibility, so that extensive pressure changes are obtained with relatively small difference of temperature. Other factors also are that all the joints and glands are cold, that a small amount of liquid, less than 1 lb. weight per hp., can be used to generate a large power output, while it is further contended that a liquid engine of this kind has the advantages of silent operation, no risk of explosion, no wastage of power medium, good efficiency at small power output, and the ability to use any kind of fuel, gaseous, liquid, and solid.

Naturally of course considerable differences of opinion must exist concerning the whole subject of the practicability and economy of using, as a commercial proposition, the expansion of a liquid for operating engines. Also much further information is required on such items as the capital cost per unit of power generated; but as to the interest of the matter there is no question.

On June 4, 1931, the inventor read a paper "A New Prime Mover" before the Royal Society of Arts, London, describing his engine and the scientific principles involved. In this connection I am

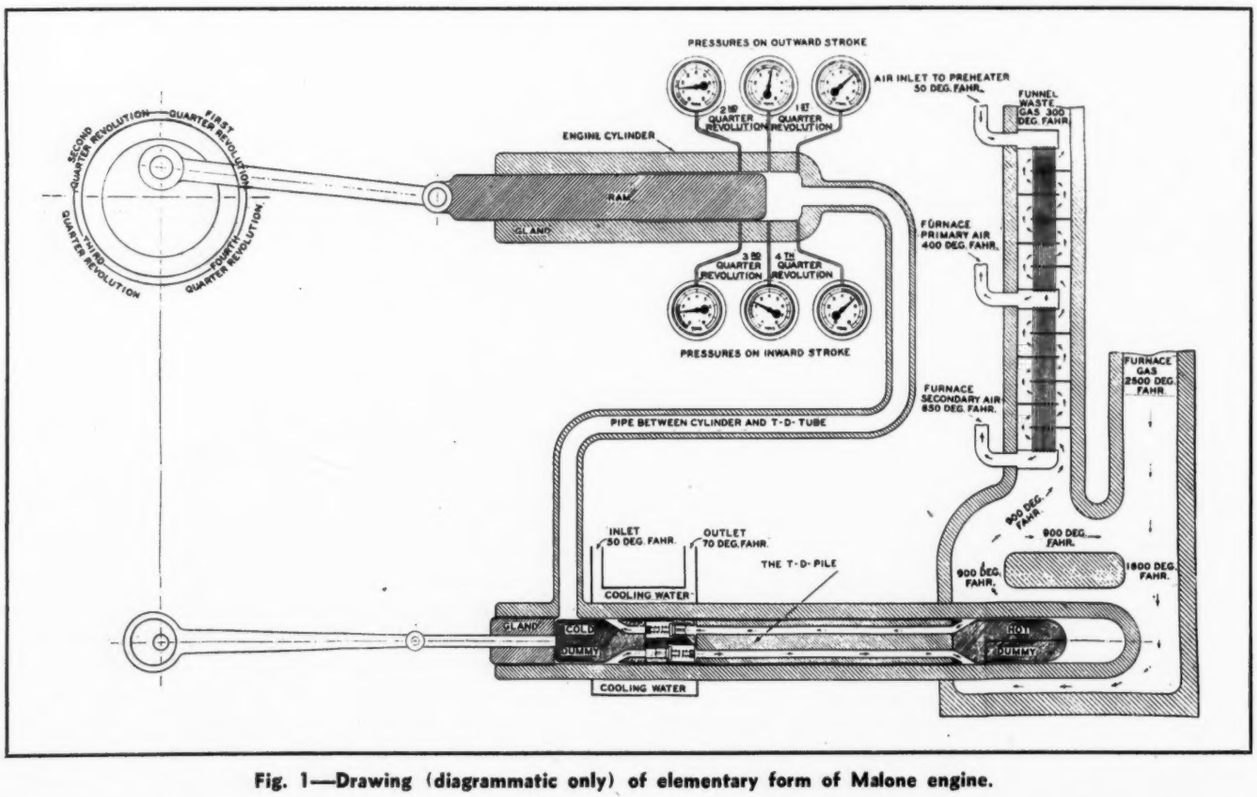

Fig. 1—Drawing (diagrammatic only) of elementary form of Malone engine.

much indebted to Mr. J. F. J. Malone and the Royal Society of Arts for permission to reproduce ("Journal of the Royal Society of Arts" June 12, 1931, pp. 680-709) the illustrations given herewith.

In Fig. 1 is shown a diagrammatic drawing of an elementary form of the Malone liquid engine, capable of being operated as a demonstration unit to illustrate the principle. The arrangement in-

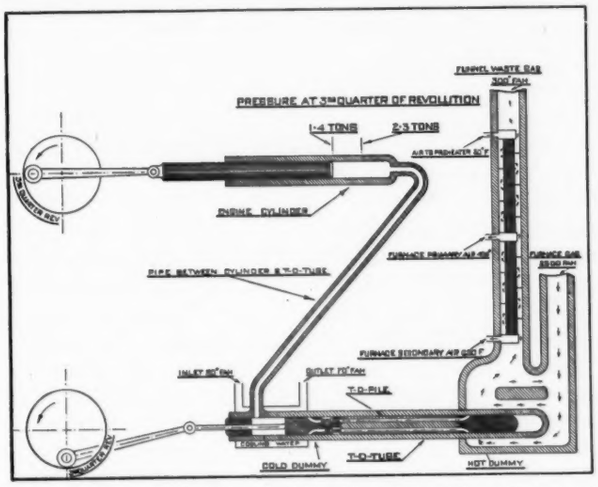

Fig. 2—Diagrammatic drawing showing T. D. pile at half-stroke position.

cludes what the inventor calls a "T. D." (thermodynamic) pile, which is a reciprocating ram or piston device operated by an eccentric on the main ram or piston crankshaft but set to move 90 deg. in advance of the latter, these being shown separated in the demonstration arrangement for simplicity and explanation. This T. D. pile is heated at one end by means of a furnace and cooled at the other by a stream of water. The engine cylinder is provided with six pressure gages, three for the inward stroke and three for the outward stroke, indicating the pressure at different stages of the ram or piston travel.

When the ram is at the right end of the engine cylinder and the T. D. pile at its mid-stroke the pressure in the circuit is about 5.3 tons per sq. in., and as soon as the engine shaft travels round the first quarter of a revolution the ram moves half a stroke out of the cylinder and the pressure falls to 4.3 tons per sq. in., while simultaneously the T. D. pile moves to the cold end of the T. D. tube. Then as soon as the engine shaft goes round the second quarter of a revolution the ram moves to the outward end of its stroke and the pressure falls to 1.4 tons per sq. in., while simultaneously the T. D. pile moves from the cold end of the T. D. tube to its half-stroke position, as indicated in Fig. 2, with the pressure at the third quarter of a revolution. When the engine shaft has moved the third quarter of a revolution, the ram travels half a stroke in the cylinder and the pressure rises to 2.3 tons per sq. in., while simultaneously the T. D. pile moves from its half-stroke position to the hot end of the T.D. tube, as seen in Fig. 3, with the pressure at the fourth quarter of a revolution. Finally at the latter stage the ram moves to the inward end of its stroke, the pressure rises to 5.3 tons per sq. in. and the T. D. pile moves from the hot end of the T. D. tube to its mid-position and so on.

The T. D. tube is a very strong steel, small diameter cylinder or tube, closed at one end, which at this point, as already indicated, is kept hot by the combustion gases from a furnace setting while the other end, having a gland and piston rod, is maintained in a cold condition by means of circulating water (or air). At each end of the T. D. pile there is operating a wider diameter portion known as a hot dummy and cold dummy respectively, connected by a heavy rod, the purpose being to provide cooling and heating surfaces on the inner walls of the T. D. tube for the water that comes into contact with them, forming an extremely thin film, stated to be only about 0.01 in. Or in other words the T. D. pile is a special arrangement whereby thin films of liquid are formed between the metal tube and the dummy heads, while at the cold end there are non-return valves, the whole arrangement being held together by the connecting rod. That is the T. D. unit is a displacer which forces the liquid through the T. D. pile from the cold end to the hot end and vice versa, the equipment also including piston springs at the valve box end of the cold dummy to prevent any liquid from passing outside the T.D. pile.

As already explained, the water moves from the hot end to the cold end during the fourth and first quarter revolutions of the engine shaft while the pressure rises from 2.3 to 5.3 tons per sq. in. and falls from 5.3 to 4.3 tons per sq. in., that is an average of 4.3 tons per sq. in. During the second and third quarter revolutions of the engine shaft the T. D. pile moves from the cold end to the hot end

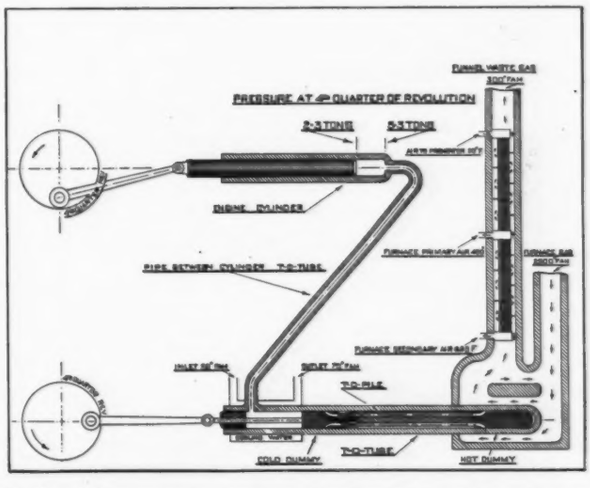

Fig. 3—Diagrammatic drawing showing T. D. pile at hot end of the T. D. tube.

of the T. D. tube while the pressure falls from 4.3 to 1.4 tons and rises from 1.4 to 2.3 tons per sq. in., an average of 2.35 tons per sq. in. Accordingly when the T. D. pile is moved from the hot end to the cold end of the T. D. tube the liquid only moves in one passage of the T. D. pile, and during this operation the moving liquid takes heat from the metal and stationary water of the T. D.

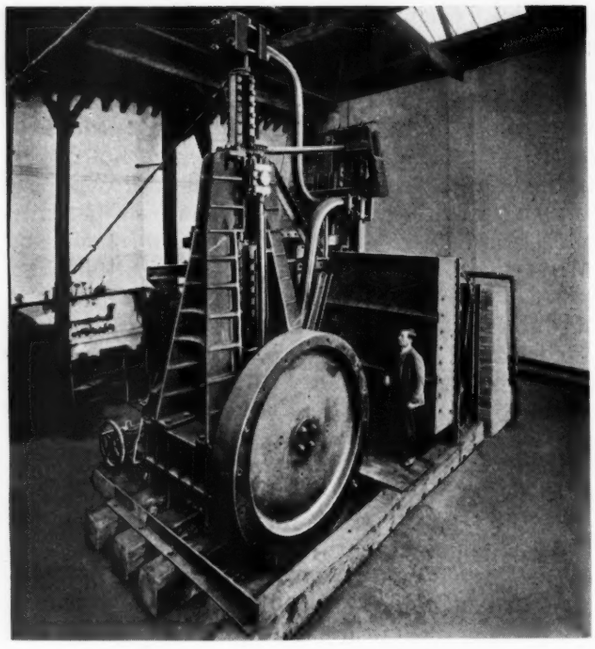

Fig. 4—Original Malone vertical engine built in 1925.

pile, while the water that surrounds the hot dummy takes heat from the heating surface of the T. D. tube under average conditions of 4.3 tons per sq. in. pressure. When, however, the T. D. pile is moved from the cold end to the hot end of the T. D. tube, the liquid only moves in the other passage of the T. D. pile, and during this operation the moving liquid gives heat to the metal and the stationary water of the T. D. pile, while the water that surrounds the cold dummy gives heat to the cooling surface of the T. D. pile, rejecting heat at an average pressure of 2.35 tons per sq. in. In simple language the great difference in pressure in the water caused by a relatively small rise in temperature causes the water to push the ram in the engine cylinder, after which it is cooled with great rapidity and so on, the whole circuit of course always being under high but varying pressures.

Further explanation of the operation is given in the inventor's original paper as follows:

"It will be noticed that the 90 deg. lead of the eccentric ahead of the crank causes the greatest movement and displacement of liquid in the T. D. pile, while the ram moves and displaces least; also that, while the ram moves and displaces most liquid, the T. D. pile moves and displaces a small amount of liquid. Hence we put heat into the liquid medium while pressure is rising, due to ram compression of liquid in the fourth quarter revolution of the engine shaft. While the ram reverses movement we put heat into the liquid medium, and cause a rise of pressure. During the first quarter revolution of the engine shaft we put heat into the liquid medium, during a small fall of pressure and a large increase of volume. During the abstraction of heat from the liquid medium we reverse the above. Hence, we have no truly adiabatic, isothermal, constant volume or constant pressure heating or cooling."

Also as indicated in Fig. 1 the arrangement includes a tubular regenerator or heat interchanger in two sections, that is essentially an air heater, to raise the temperature of the incoming cold air by the outgoing combustion gases which are stated to be 2500 deg. fahr. from the furnace, 900 deg.

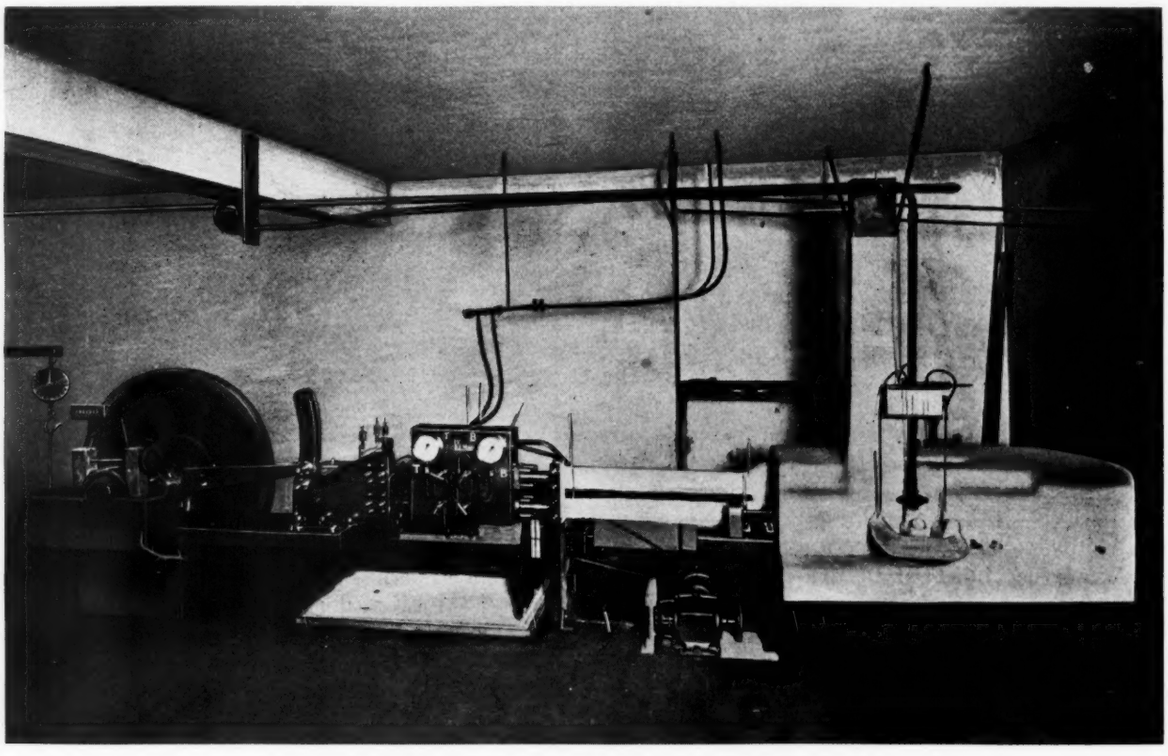

Fig. 5—Malone horizontal engine built in 1930.

fahr. after leaving the T. D. tube, and 300 deg. fahr. passing to the chimney, the primary air being raised to 400 deg. fahr. and the secondary air having a temperature of approximately 650 deg. fahr.

As pointed out by the inventor, the engine in some features resembles the original hot air engine, that is the medium does not undergo any chemical or physical change (from a liquid to a gas) and is exposed at any instant to approximately the same pressure, while there is no exhaust but the installation includes the air heater or regenerator. The differences of course as compared with a hot air engine apart from the use of liquid instead of gas, are that the quantity of the heat in the regenerator is much greater than the quantity in the rest of the apparatus, the engine does several revolutions to make the medium move once round the circuit, and the flow in the regenerator is always in one direction.

The first large engine, constructed in 1925, which was of crude and cumbersome design as shown in the photograph, Fig. 4, ran on oil for a few days and then water was employed, which is now the standard practice. Many liquids have been tested in one or another of the various engines, including various metals, and petrol, alcohol, liquid CO_2 and liquid SO_2. The ideal liquid must have a stable and uniform specific heat, compressibility proportionate to its dilatation, and great resistance to chemical dissociation, while combustible, explosive, and poisonous properties should be absent as far as possible. In general mercury is satisfactory although inferior to water, but oils are too viscous at low temperature or too chemically unstable at high temperatures, while sodium, potassium, and alloys of these metals are dangerous, and most metallic alloys have too high a melting point.

The first vertical engine built in 1925 had 80 large tubes and two engine cylinders, and extensive experiments were carried out with this unit in the period from 1925 to 1927, while the art of operation, power control and reversibility was learned in practical fashion using a setting with coal and coke as fuel. Also the T. D. piles, 80 in number, were operated by a cam device instead of the eccentric, the speed varying from 24 to 180 r.p.m. Later an eccentric drive was found to be more satisfactory and was adopted.

In 1930, a small horizontal engine was built which has since remained in constant use for experimental and demonstration purposes, having run well over 30,000,000 revolutions, with speeds varying from 40 to 250 r.p.m. Subsequently a second vertical engine was also built with 20 small tubes and two engine cylinders, and much further experimental work was carried out with this unit.

It is claimed that as the average of detailed tests carried out by three independent engineers, the average indicated thermal efficiency is 27 per cent and that after making full allowance for the furnace and mechanical losses a commercial engine of 100 boiler hp. or upwards will run at 20 per cent overall efficiency from the raw coal to the power shaft, while the approximate weight would be 330 lb. per i.hp.

In general this performance corresponds to 12,725 B.t.u. per boiler hp. and 10,816 B.t.u. per i.hp. that is 0.61 lb. oil and 0.87 lb. of good coal per boiler hp. or 0.51 lb. oil and 0.74 lb. coal per i.hp. Further claims are that for railway practice a Malone liquid engine of this kind would give more power for half the coal consumption and no water consumption while having a greater starting effort as compared with the steam locomotive, at the same time being free from gears and without any increase in weight, cost, and space. Also the invention is now stated to be ready for commercial development.

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Oklahoma Natural Gas Company announces that E. C. Deal has resigned the presidency to become chairman of the board of directors, and that E. A. Olsen, former executive vice president, has been elected president.

Mr. Olsen has had a long identification with public utility work, having served as executive vice president of the Florida Power Corporation, and having had similar operating responsibilities with the Georgia Power & Light Company, and West Florida Power Company and the Florida West Coast Ice Company. Just prior to his identification with the Oklahoma Natural Gas Corporation, he was operative vice president of the Pacific Public Service Company, in which capacity he had much to do with the large diameter transmission lines from the famous Kettleman Hills natural gas field to the great industrial area of San Francisco bay, and was in charge of the changing over from manufactured gas to natural gas.

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Stevens & Wood, Inc.: Following the dissolution in October of Allied Engineers, Inc., announcement has been made that Stevens & Wood, Inc. has been reorganized, with offices at 120 Broadway, New York. The latter firm was absorbed by Allied Engineers, Inc. in April, 1930. The new Stevens & Wood organization will continue in the same line of work as the original concern, i.e., the design and construction of power plants. The principals of the firm are R. T. Stevens and B. F. Wood, both of whom have had conspicuous identification with a number of this country's leading power stations.

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Richard T. Crane Dies

R. T. Crane, President of the Crane Company, Chicago, Ill., died on November 7th in New York where he had come for medical treatment. Mr. Crane entered the employ of the Crane Company, which his father had founded in 1855, the year after his graduation from Yale in 1895. In 1898 he became second vice president, and in 1914 president. His death occurred on his 58th birthday.

The Combustion of Mixed Fuels

IT is common practice to equip boilers with combination furnaces wherein two or more fuels may be burned simultaneously. This is especially true of plants where so-called waste fuels are used, the supply of which is inadequate or not dependable.

This practice has been rapidly extended within the past few years due principally to improved burner designs and to a better utilization of the principles of turbulence in the furnace as well as in the burner. The watercooled wall has greatly facilitated the attainment of conditions of turbulence and temperature essential to the maintenance of proper ignition without the aid of refractory surfaces, even with low heat value fuels, such as blast furnace gas. As a result of these developments, various combinations of fuels are being burned with high overall efficiency, and the operating difficulties which characterized earlier efforts in this direction have been entirely eliminated.

The most common combination of fuels is blast furnace gas and coal or oil and natural gas or oil-still gas with oil.

If the quantities of each fuel burned are known, the composition of the composite fuel may be calculated and combustion data may be computed by the standard methods. Often, however, the amount of one or both of the fuels is not measured but only the total known from the amount of steam generated. In such cases the proportions of the two fuels may be determined from the flue gas analysis.

When two fuels such as blast furnace gas and coal or blast furnace gas and oil are burned together, the carbon dioxide content of the flue gas will be a measure of the proportions of the mixture. Fortunately, with these two combinations, there is a large difference in per cent CO_2 for the two extremes of the proportion.

The method used to determine the component proportions of mixed fuels is illustrated by the chart on the opposite page. From the ultimate analysis of each component, the analyses of various mixtures is computed and the per cent carbon dioxide for zero excess air is calculated. The curves A-B which give the per cent CO_2 with zero excess air for different mixtures is thus constructed.

For use with this chart the gas analysis must be reduced to zero excess air. The free oxygen in the analysis may be considered to come all from the air used for combustion and it and a corresponding amount of nitrogen must be subtracted and the carbon dioxide and remaining nitrogen recalculated as per cent. Thus, in the following analysis:

$$\begin{aligned} CO_2 &= 17.4 \text{ per cent} && = 17.4 = 20.4 \text{ per cent} \\ O_2 &= 3.1 \text{ per cent} - 3.1 && = 0 = 0 \text{ per cent} \\ N_2 &= \frac{79.5}{100} \text{ per cent} - (3.1 \times 3.78) && = \frac{67.8}{85.2} = 79.6 \text{ per cent} \end{aligned}$$

the oxygen 3.1 parts is subtracted and if the nitrogen (3.1 × 3.78) or 11.7 parts is subtracted, the remaining carbon dioxide and nitrogen are then computed in per cent giving 20.4 per cent and 79.6 per cent respectively. From the curve for blast furnace gas and coal it may be seen that this per cent CO_2 corresponds to a mixture of 30 per cent by weight coal and 70 per cent blast furnace gas. Obviously, the gas sample must be representative and the results from a single sample should not be depended upon.

The fuel analyses in per cent by weight used in the preparation charts are given below:

	Blast Furnace Gas	*Bituminous Coal*	*Fuel Oil*
Carbon	16.5 per cent	74.4 per cent	85.5 per cent
Hydrogen	.1 per cent	4.7 per cent	11.5 per cent
Oxygen	27.5 per cent	6.7 per cent	.7 per cent
Nitrogen	55.9 per cent	1.4 per cent	.7 per cent
Sulphur	.....	1.0 per cent	1.6 per cent
Ash	.....	8.4 per cent	.....
Moisture	.....	3.4 per cent	.....

While the purpose of the charts is chiefly to illustrate the method, it may be used where the analyses of the fuels do not differ greatly from those given above.

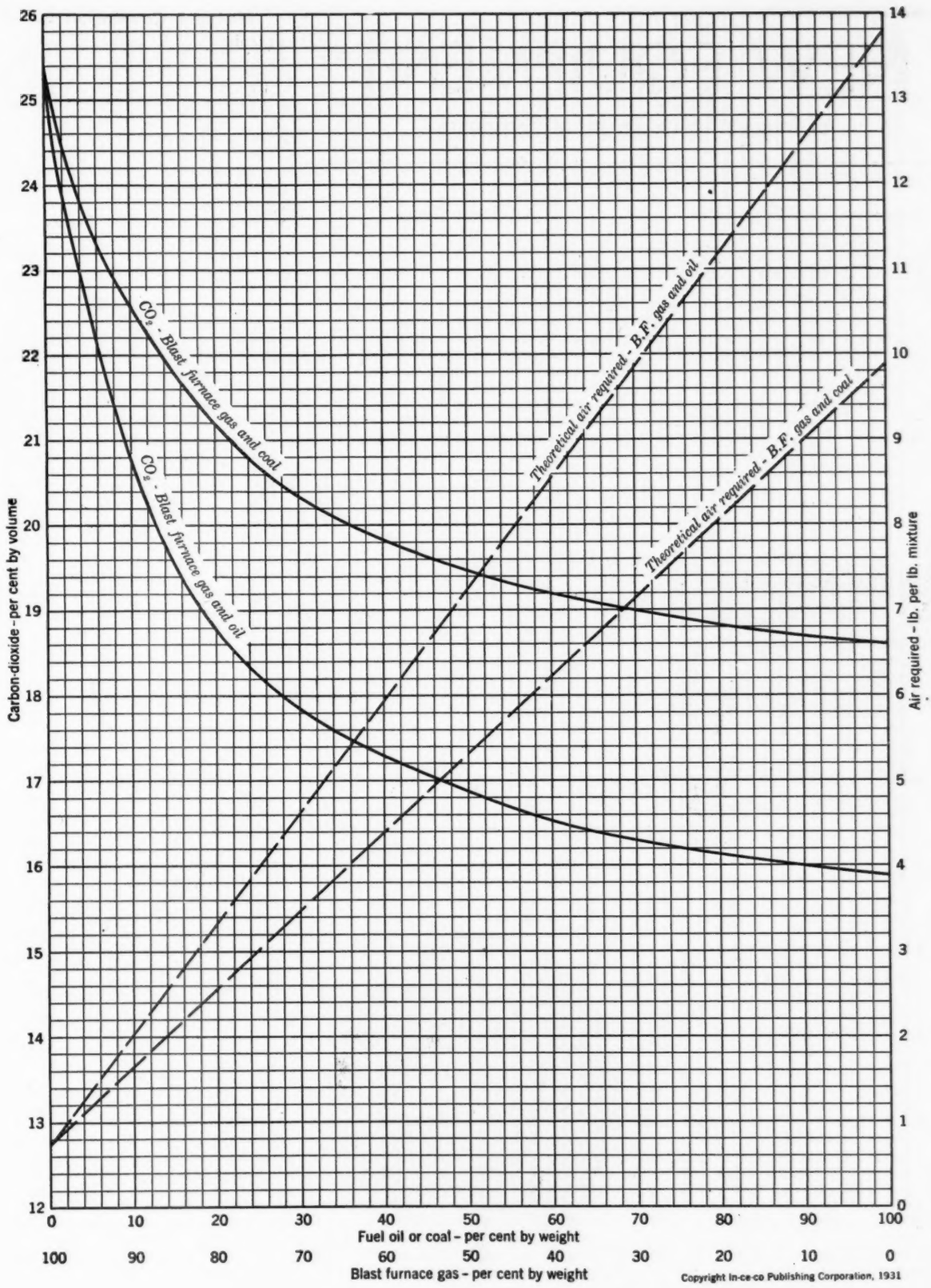
Carbon-dioxide - per cent by volume
Air required - lb. per lb. mixture
CO_2 - Blast furnace gas and coal
CO_2 - Blast furnace gas and oil
Theoretical air required - B.F. gas and oil
Theoretical air required - B.F. gas and coal
Fuel oil or coal - per cent by weight
Blast furnace gas - per cent by weight
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CHART FOR DETERMINING THE PROPORTION OF THE COMPONENTS OF FUEL MIXTURES FROM FLUE GAS ANALYSIS

No. 30 of a series of charts for the graphical solution of steam plant problems.

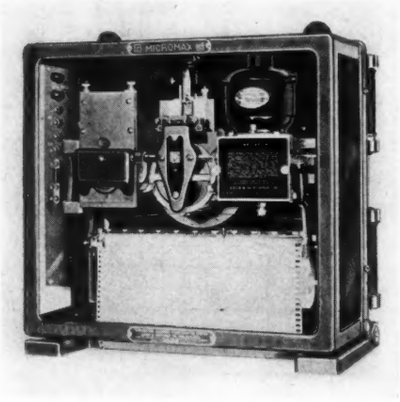
NEW EQUIPMENT

of interest to steam plant Engineers

Potentiometer Pyrometer

The improved L & N Potentiometer Pyrometer, Micromax. recently announced by the Leeds & Northrup Company of Philadelphia, has advantages that will be readily recognized by pyrometer users who appreciate pyrometer reliability.

In Micromax, the potentiometer pyrometer is raised to a new high level of accuracy, reliability and strictly automatic operation. This improved instrument requires no manual adjustments. It needs no daily attention. It eliminates the "human element" in potentiometer pyrometer operation. The instrument circuit is standardized automatically, every 45 minutes or less, giving a closer adjustment than is obtained manually. And manual



adjustment of the stepping action is no longer necessary. Micromax is in every detail, a fully automatic potentiometer pyrometer.

By virtue of its microscopically sensitive balancing device, Micromax can detect and record deflections of the galvanometer pointer amounting to 1/1000th of an inch. Micrometer sensitivity makes the recorder action responsive and speedy, sending the pen, or print wheel, across the chart paper in steps that are much more accurately proportionate to the temperature change. If necessary, the recording pen, or print wheel, can step across the entire chart in less than 22 seconds, the size of each step being closely related to the extent of galvanometer pointer deflection. It is evident, especially in automatic control and where more than one temperature is being measured, that the rapid recording feature of the Micromax pyrometer is a long-desired and looked-for advance in industrial temperature control.

Micromax is put forward by its makers as a basic contribution to the advancement of industrial pyrometry. Micrometer sensitivity, automatic standardization and rapid recording are now combined with the established accuracy and reliability of the potentiometer circuit.

Notice has been received from the Leeds & Northrup Company, that all models of Micromax have been in full production for several weeks.

All-Steel Gages

The Crosby Heavy Duty, All-Steel Gage, Style AIH, is designed to give exceptional accuracy and long life on severe service where rapidly pulsating pressures and vibration quickly wear out regular gages, such as on high pressure, high temperature oil cracking, modern high pressure steam stations, and synthetic chemical plants. It is unaffected by many chemicals and fumes which attack bronze, such as sulphur and ammonia.

The tubes are completely machined from a solid bar of special alloy steel. The machining includes precision boring and turning, absolutely concentric, and the threading of the heavy and sections. The tubes are rolled to shape and radius, heat treated and tempered. All work is done under exact control.

The tube is attached to socket and tip by threads forming a mechanical joint which will not fail should high temperature fluid reach the tube.

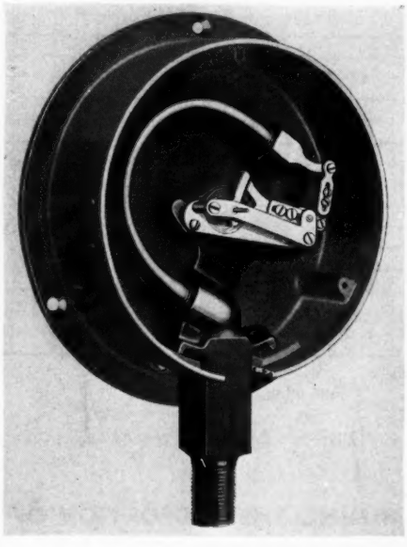
The movement, entirely of steel, is exceptional in design and material.

The bearings are of stainless steel hardened and polished.

The sector and pinion are wide-faced and forged to give the tough core required to withstand the blow of extreme vibration and pulsation which will break hard brittle teeth. The teeth are machined (not punched or broached), then hardened and chromium-plated to resist wear.

The complete operating mechanism of the gage is independently mounted on the socket and is, therefore, unaffected by stress applied to or distortion of the case.

The socket is of forged steel, of exceptionally sturdy design and section. It



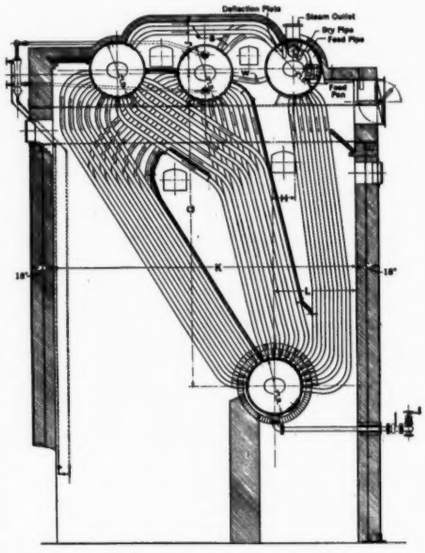
extends well below the case and is milled to provide a wrench-fit invaluable in making up a tight joint on high pressure.

The case is dust and moisture proof.

Multiple Circulation Boiler

Combustion Engineering Corporation, 200 Madison Avenue, New York, has recently developed a new type of boiler which provides a logical solution to the problem of insuring adequate circulation and correct steam liberation under the most severe conditions of operation. This boiler is now offered to the steam generating industry in sizes ranging from about 2,000 sq. ft. to 26,000 sq. ft. of heating surface. It is adaptable to any type of firing and may be set double.

The salient features of this development are as follows: The C-E Multiple Circulation Boiler departs from the con-



ventional design in two essentials—tube arrangement and steam liberation.

The tubes in the first pass of the boiler are arranged so that half of them enter the front drum and the other half enter the middle drum. The tubes in the second pass are arranged so that half the tubes enter the middle drum and the other half enter the front drum.

The unique tube arrangement effects a double circulation in the boiler. One circulation is up half the tubes in the front tube-bank to the front upper drum, then down the tubes running into the middle tube-bank to the lower steam and water drum. The other circulation is up the other half of the tubes in the front tube-bank which run into the middle upper drum then down half the tubes in the middle tube-bank to the lower steam and water drum.

This splitting of the circulation results in equalizing the steam liberation in the upper front and middle drums and thus eliminating the intense turbulence which is present in the conventional types of multi-drum bent tube boilers, in which the greater part of the steam is liberated in the front drum—consequently the many disadvantages which accompany such turbulence are also eliminated.

In order to assure dry steam production, the steam circulators are increased in number over the conventional design. A further change in design consists in connecting the steam circulators from both the front drum and the middle drum directly into the rear drum. This design effects two improvements over the conventional boiler, namely, drier steam and greater steam velocity. The high rate of circulation results in a minimum of scale deposit.

REVIEW OF NEW TECHNICAL BOOKS

Any of the books reviewed on this page may be secured from In-Ce-Co Publishing Corporation, 200 Madison Avenue, New York

Heat Engines

By John R. Allen and Joseph A. Bursley

THE 1931 edition of this book is the fourth edition published since the first edition was printed in 1910. In the preface to the 1931 edition it is stated that the volume, while enlarged to encompass the many changes characteristic of present-day practice, has not been changed in style and is still intended to serve the purpose of an elementary text.

The following list of chapter headings indicate the content and scope of the book,—Heat; Elementary Thermodynamics; Properties of Steam; Calorimeters and Mechanical Mixtures; Fuels and Combustion; Boilers; Boiler Auxiliaries; Steam Engines; Testing of Steam Engines; Compound Engines; Valve Gears; Governors; Steam Turbines; Condensers; The Internal Combustion Engine; Fuels and Fuel Systems; Auxiliary Systems; Rating and Performance; Economy of Heat Engines.

Each of these subjects is presented in such a manner as to permit a clear understanding of the principles involved by a reader of limited technical education. At the end of many of the chapters, several examples are given which enable the student to test his grasp of the material.

Altogether this is an excellent text book not only for the student engineer but also for the practical engineer who wishes to add to his technical appreciation of the equipment and operations under his charge.

This book is 6½ x 9½ and contains 540 pages. Price $4.00.

A. S. T. M. Tentative Standards, 1931

THIS valuable book, published by the American Society for Testing Materials, contains the 180 tentative specifications, methods of test, definitions of terms and recommended practices in effect at the time of its publication.

The items covered include ferrous and non-ferrous metals, cement, lime, gypsum, concrete and clay products, and a great number of miscellaneous materials. The term "tentative" as defined by the Society, applies to a proposed standard published for one or more years, with a view of eliciting criticism, before it is formally adopted as standard by the Society. The tentative standards submitted or revised in any given year appear in the Proceedings of the Society for that year. In addition, all tentative standards in effect in any given year are published collectively in a Book of A.S.T.M. Tentative Standards which is issued each year about October 15, the present volume containing those in effect as of September, 1931.

Containing all the tentative standards, the Book of Tentative Standards should prove most convenient for reference purposes. The specifications and methods of test, although still in the trial stage of the A.S.T.M. procedure, represent the latest thought of the committees on the subjects covered and therefore are finding important applications in the various industries. Since the tentative standards may frequently be used in conjunction with A.S.T.M. standards, the volume is complementary to the volumes containing the standards, namely, the Book of A.S.T.M. Standards (Part I on Metals and Part II on Non-Metallic Materials) with its supplements.

The volume also includes proposed revisions of standards, published as tentative with a view of eliciting criticisms, of which the committees concerned will take due cognizance before recommending final action.

This book is 6 x 9 overall and contains 1008 pages. It is available in both cloth and paper covers, the cloth cover being priced at $8.00 and the paper at $7.00.

Handbook of Oil Burning

THIS handbook contains information of very practical value to the engineer or contractor whose work requires a knowledge of oil burning heating or power equipment. In addition to authoritative information, charts, tables and descriptive illustrations relating to every phase of the oil burner industry, the handbook contains a thorough treatise on industrial application of oil as a fuel, with drawings, illustrations and tables covering this type of installation. The handbook also discusses in detail the different types of oil burner and principles of construction, oil burner controls and motors and fuel oil tanks and storage. A wealth of general information such as the chemistry of combustion and flame, fundamentals of heat and heat transfer, the determination of heating capacity requirements and comparative fuel costs also is included.

This book contains 629 pages including 123 tables and 358 illustrations and charts spread over 24 chapters. The overall dimensions are 5 by 7½. Price $3.00.

NEW CATALOGS AND BULLETINS

Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine

Bent Tube Boilers

Catalog No. 69 describes Edge Moor Boilers of the four-drum, three-drum and horizontal bent-tube types. Following the section of the catalog devoted to the description and illustration of these three types, there is a section on shop practices and a section showing blue prints of typical applications. The catalog throughout is exceptional in the quality of its printing and reproduction of illustrations. 32 pages and cover, 8½ x 11—Edge Moor Iron Company, Edge Moor, Delaware.

Electrical Instruments

New Catalog GEA-602A furnishes information on standard lines of switchboard, portable and laboratory instruments. Dimensions, typical scales and wiring diagrams on certain lines are included, together with tables of specifications and prices. The main index lists and classifies the various instruments under three headings, Switchboard Indicating Instruments, Switchboard Recording Instruments and Portable Indicating Instruments. 146 pages and cover, 8 x 10½—General Electric Company, Schenectady, N. Y.

Feed Water Treatment

"Buromin," a new term to be used as the trade name for Hagan phosphate in liquid form, is described in a new pamphlet. Buromin makes available to smaller plants the principles of feed water treatment used in the Hall System, which system is controlled by basic patents and is only available by license agreement. The pamphlet describes the development of the Hall System and Hagan phosphate, and tells how this development is now made available through Buromin, in a simple and easily applicable form which will provide smaller plants with all the practical results of the Hall System without the necessity for operating under the conditions ordinarily involved in the use of this system. 4 pages, 8½ x 11—The Buromin Co., 309 Bowman Building, Pittsburgh, Pa.

Flexible, Seamless, Metal Hose

Seamlex flexible seamless metal hose is described in Bulletin No. 311 which shows illustrations of the various types of Seamlex. These include 12 sizes ranging from 1/16 in. to 2 in. inside diameter, and designed for different conditions of pressure, temperature, banding, etc. Seamlex is made of seamless metal tubing of special analysis, is leakproof and highly flexible, and can be used for handling gases, steam or liquids. 8½ x 11—Seamlex Corporation, 1028 - 47th Ave., Long Island City, N. Y.

Gear Pumps for Liquids

Schutte & Koerting gear pumps for oils and other liquids are described in Bulletin 17-A. The various types of pumps described include the spur gear pump, herringbone gear pump; also herringbone gear pump sets, twin and triple gear pumps. Illustrations are shown of motor-driven and turbine-driven gear pumps arranged for both belt and gear drive. Tables relative to the various pumps and pump sets give full details, including capacities, size of motor, weight, dimensions, list price, etc. 24 pages, 8 x 11—Schutte & Koerting Company, Philadelphia, Pa.

Hoists, Cranes, Trolleys

Wright hoists, cranes and trolleys are described in Catalog No. 15, which shows illustrations and gives detailed information concerning Wright High Speed Hoists, Screw Hoists, Differential Hoists, Army Type Trolley Hoists, Low Headroom Trolley Hoists, Roller Bearing Trolleys, Clevis Connected Hoist and Trolley, Extended Handwheel Hoists, Twin Hook High Speed Hoists, Quick-Lift Hoists, High Speed Hand Winches, Jib Cranes, Sling Chains, Hand Traveling Cranes and Electric Hoists. 16 pages and cover, 4½ x 10¾—Wright Manufacturing Company, Bridgeport, Conn.

Industrial Control Equipment

General Electric devices for various types of control are described in Catalog GEA-606C. This catalog is divided into 13 sections covering items which may be roughly classified as follows: A-c and D-c Hand Starters; A-c and D-c Speed Regulators; Accessories; D-c Drum Switches and Resistors; A-c Drum Switches and Resistors; D-c Magnetic Controllers; A-c and D-c Printing Press Controllers; A-c Magnetic Controllers; Rheostats and Resistors; Limit Switches; Solenoids, Solenoid Valves, and Brakes. The last two sections are devoted to general information and indexes. 196 pages and cover, 8 x 10½—General Electric Company, Schenectady, N. Y.

Liquid Level Controller

The Mercon Liquid Level Controller is described in Bulletin No. 4c. Drainage and filling controllers are illustrated. The features claimed for the drainage controller are adjustable capacity, graduated valve travel, ample operating force and adjustable level. The features of the filling controller are adjustable neck, jacking device, perfect alignment and interchangeability to the drainage type. 4 pages, 8½ x 11—The Mercon Regulator Company, 1 La Salle Street, Chicago, Ill.

Oil Burners

A number of improved types of Enterprise oil burners are featured in a new catalog just published. This catalog presents complete illustrations and details of the burners, with specifications and data on fuel consumption and vital heating statistics of interest to those using or specifying burners. It includes burners for application in power plants, where boilers are used, all types of industrial buildings, office buildings, homes and for marine service. The catalog includes a new small oil burner known as AAA, adaptable to all types of heating units requiring a limited amount of combustion. A number of accessories manufactured by the firm are also included. 32 pages, Enterprise Oil Burner Company, 2902 19th St., San Francisco.

Potentiometer Pyrometer

The new Brown Potentiometer Pyrometer is described in a pamphlet just issued. This potentiometer is an entirely new instrument, containing more than 50 new features. Some of the features described are galvanometer sensitivity, accuracy due to long slide wire, pen driven by spiral steel shaft, positive non-slip drive clutch, all working parts protected, unusually wide chart, entire mechanism swings out for inspection, humidity compensator for chart, and temperature equalization. 16 pages, 8 x 10½—The Brown Instrument Company, Wayne and Roberts Avenues, Philadelphia, Pa.

Steam Pressure Regulator

The Brooke Regulator is described and illustrated in Bulletin H-3. This regulator is of the constant pressure type, electrically actuated and requiring no water or compressed air. The bulletin includes steam pressure charts, recording performance with and without the use of the regulator. 6 pages, 8½ x 11—Brooke Engineering Company, Inc., 3640 N. Lawrence Street, Philadelphia, Pa.

Variable Speed Transmissions

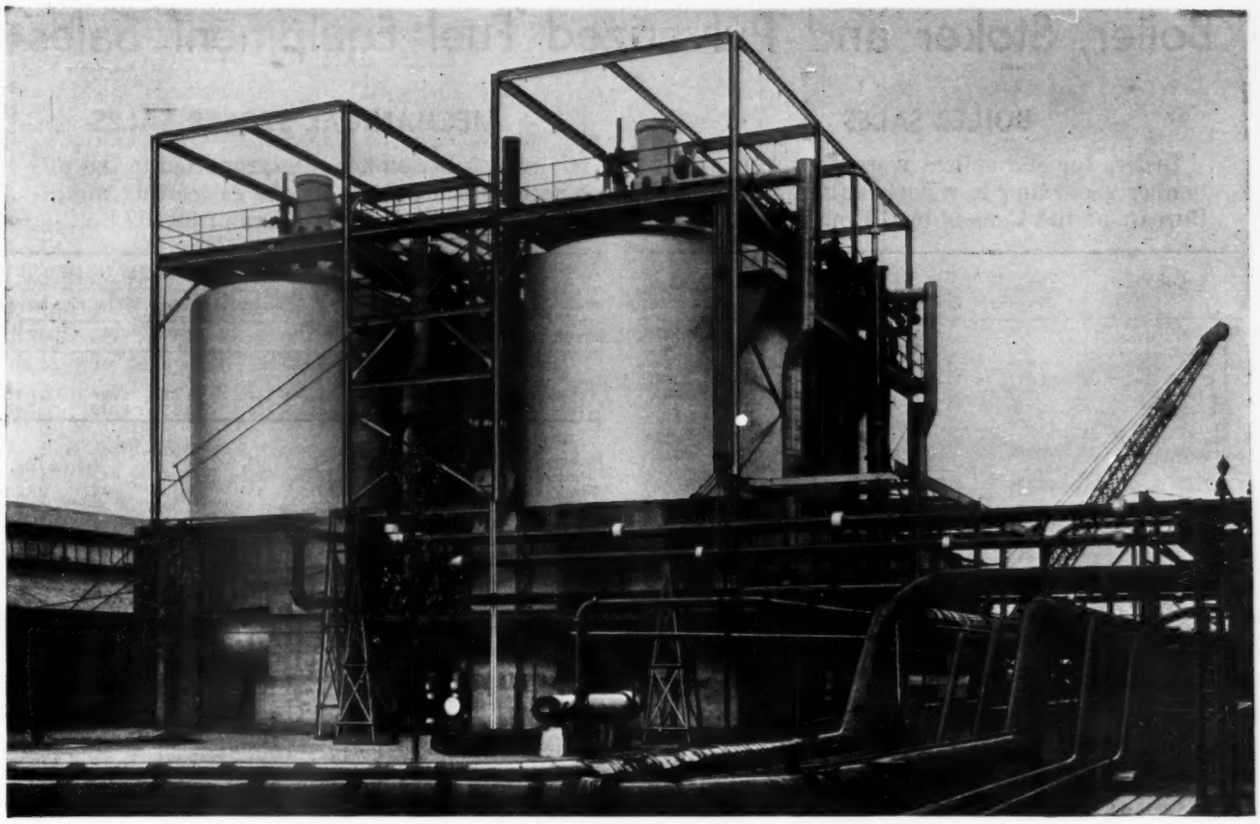
Reeves Variable Speed Transmissions are described in new catalog, No. 99. Part I of this catalog is devoted to construction and operating principles, with numerous illustrations of the complete Reeves line; Part II is devoted to designs, remote controls and accessories; Part III to automatic speed control; Part IV to standard equipment application; Part V to specific uses in a number of different industries; and Part VI to engineering information which includes tables of sizes, classes, speeds, dimension diagrams and efficiency charts. 74 pages and cover, 8½ x 11—Reeves Pulley Company, Columbus, Ind.

NOTICE

Manufacturers are requested to send copies of their new catalogs and bulletins for review on this page. Address copies of your new literature to

COMBUSTION

200 Madison Ave., New York



The J. G. White Engineering Corp., Engineers and Contractors

A 420,000 Gallon Per Hour COCHRANE HOT PROCESS SOFTENER

AT NEWGULF, TEXAS, sulphur deposits are melted in place 800 to 1100 feet below the surface and the melted sulphur pumped up by air lift. Heat for melting the sulphur is supplied by hot water from a Cochrane Hot Process Softener and Cochrane Jet Heaters using steam at 100 lbs. gage. The purpose of the softener is to prevent the deposit of scale in the piping system, in addition to supplying the boilers with hot, softened water.

The Cochrane Softener consists of six units, each of 70,000 gal. per hour capacity, and is believed to be the largest hot process water softener in the world, and probably the largest water softener of any description serving an industrial plant. The shipment of the first four softener units and of the first three Cochrane Jet Heaters, which were installed in 1928, required 32 freight cars.

The water which is to be pumped into the earth is first heated in heat exchangers by means of the drainage water which escapes from the drainage wells at about 120 deg. F. It is then further heated in the Hot Process Softener to a little above 212 deg. F., after which it is treated chemically and settled and then further heated in the jet heaters. The water for the boilers is treated with sodium sulphate and phosphate to control the sulphate to carbonate ratio and the caustic alkalinity of the boiler water to avoid embrittlement.

Engineers, generally, acclaim the Cochrane Hot Process Softener as BEST FOR BOILERS.

If you are interested, ask for Publication C-1746, "Hot Lime-Soda-Phosphate Treatment of Feed Water for High Pressure Boilers."

COCHRANE CORPORATION

3160 North 17th Street, Philadelphia, Pa.

Boiler, Stoker and Pulverized Fuel Equipment Sales

BOILER SALES

Orders for 893 boilers were placed in September according to reports submitted to the Bureau of the Census by 73 manufacturers.

Month	1930 Number	1930 Square feet	1931 Number	1931 Square feet
January	942	1,081,749	598	576,723
February	873	938,906	516	622,343
March	977	1,263,709	630	664,784
April	1,017	1,070,093	689	825,203
May	1,283	1,329,748	658	603,401
June	1,360	1,588,553	818*	677,434*
July	1,309	1,410,096	816	687,058
August	1,371	1,356,751	827	594,698
September	1,254	1,282,388	893	692,238
Total (9 mo.)	10,386	11,321,993	6,445	5,943,882
October	1,189	851,525		
November	777	709,322		
December	814	587,053		
Total (Year)	13,166	13,469,893		

* Revised.

TOTALS FOR FIRST 9 MONTHS AND NEW ORDERS, BY KIND, PLACED IN SEPTEMBER, 1930-1931

Kind	1930 No.	1930 Sq. ft.	1931 No.	1931 Sq. ft.	Sept., 1931 No.	Sept., 1931 Sq. ft.
Stationary:						
Total	10,175	10,301,418	6,303	5,469,315	875	621,136
Water tube	906	4,815,193	556	2,353,051	54	219,759
Horizontal return tubular	739	1,002,906	404	506,193	60	73,421
Vertical fire tube	897	275,840	475	129,579	48	10,609
Locomotive, not railway	131	107,713	77	68,681	6	4,497
Steel heating	6,181	2,775,864	4,167	1,823,249	640	249,766
Oil country	856	976,736	338	382,365	29	33,640
Self contained portable	348	243,848	233	178,717	30	27,329
Miscellaneous	117	103,318	53	27,480	8	2,115

MECHANICAL STOKER SALES

September stoker sales, reported to the Bureau of the Census by the 21 leading manufacturers, totaled 96 stokers of 22,462 hp.

Year and Month	TOTAL No.	TOTAL H.P.	INSTALLED UNDER Fire-tube boilers No.	Fire-tube boilers H.P.	Water-tube boilers No.	Water-tube boilers H.P.
1929						
Total (First 9 mo.)	1,352	459,032	544	81,613	808	377,419
Total (Year)	1,716	599,585	706	102,515	1,010	497,070
1930						
January	53	13,198	24	2,872	29	10,326
February	73	22,648	26	3,732	47	18,916
March	89	32,403	45	6,128	44	26,275
April	108	35,903	46	6,984	62	28,919
May	96	31,956	41	5,703	55	26,253
June	151	47,803	70	10,100	81	37,703
July	150	37,761	83	11,434	67	26,327
August	115	29,988	61	10,587	54	19,401
September	128	42,899	71	9,186	57	33,713
Total (9 mo.)	963	294,559	467	66,726	496	227,833
October	92	38,276	46	5,148	46	33,128
November	71	21,103	41	5,731	30	15,372
December	53	11,726	35	5,307	18	6,419
Total (Year)	1,179	365,664	589	82,912	590	282,752
1931						
January	85	25,902	40	6,719	45	19,183
February	67	14,249	37	5,326	30	8,923
March	63	17,993	27	4,509	36	13,484
April	65	18,723	32	5,192	33	13,531
May	80	23,646	29	4,341	51	19,305
June	111	29,889	55	8,519	56	21,370
July	101	20,735	58	8,283	43	12,452
August	132	31,171	59	8,318	73	22,853
September	96	22,462	56	8,720	40	13,742
Total (9 mo.)	799	204,370	393	59,927	406	144,443

PULVERIZED FUEL EQUIPMENT SALES

September orders for coal pulverizers as reported to the Bureau of the Census aggregated 7 pulverizers having a total capacity of 13,600 lb.

Year and Month	STORAGE SYSTEM PULVERIZERS Total Number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb. coal/hr. for contract	STORAGE SYSTEM BOILERS Number	Total sq. ft. steam generating surface	Total lb. steam per hour equivalent	DIRECT FIRED OR UNIT SYSTEM PULVERIZERS Total Number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb. coal/hr. for contract	DIRECT FIRED OR UNIT SYSTEM BOILERS Number	Total sq. ft. steam generating surface	Total lb. steam per hour equivalent
FOR INSTALLATION UNDER WATER-TUBE BOILERS														
1931														
January	2	2	..	60,000	1	51,177	704,000	8	4	4	40,500	9	42,970	412,675
February	1	..	1	40,000	1	29,100	375,000	2	2	..	8,000	1	7,570	75,000
March	2	2	..	60,000	..	.....	.....	13	13	..	122,000	8	93,960	1,404,000
April	2	2	..	60,000	1	34,300	592,000	9	8	1	49,250	6	46,300	538,200
May	..	..	..	.....	..	.....	.....	..	..	..	.....	..	.....	.....
June	..	..	..	.....	..	.....	.....	14	6	8	59,360	11	56,080	530,290
July	..	..	..	.....	..	.....	.....	11	8	3	114,600	8	117,000	1,088,980
August	..	..	..	.....	..	.....	.....	4	4	..	25,000	4	16,725*	110,250*
September	..	..	..	.....	..	.....	.....	3	2	1	9,250	3	2,682	86,600
Total (9 mo.)	7	6	1	220,000	3	114,577	1,671,000	64	47	17	427,960	50	383,287	4,245,995
FOR INSTALLATION UNDER FIRE-TUBE BOILERS														
1931														
January	..	..	..	.....	..	.....	.....	6	..	6	6,000	6	7,500	53,350
February	..	..	..	.....	..	.....	.....	3	..	3	2,250	3	3,000	22,350
March	..	..	..	.....	..	.....	.....	2	1	1	2,750	1	3,004	22,500
April	..	..	..	.....	..	.....	.....	1	..	1	4,000	2	6,700	45,000
May	..	..	..	.....	..	.....	.....	3	1	2	3,800	3	6,000	27,000
June	..	..	..	.....	..	.....	.....	4	1	3	4,000	4	5,750	22,100
July	..	..	..	.....	..	.....	.....	5	3	2	3,900	5	8,000	47,700
August	..	..	..	.....	..	.....	.....	4	1	3	4,250	4	7,307*	43,600*
September	..	..	..	.....	..	.....	.....	4	4	..	4,350	5	5,000	22,500
Total (9 mo.)	..	..	..	.....	..	.....	.....	32	11	21	35,300	33	52,261	306,100

* Revised.

The Plant Storeroom

(*Continued from page 38*)

ered by marker No. 1 are withdrawn, each card being considered separately. After entering the date, the quantity on hand is next entered. If the "Maximum" and "Minimum" have not yet been entered, these should next receive attention. Then if the quantity on hand is above the minimum, an "O" is placed in the "Short" column. If below the minimum a check mark should be used. The entries being completed, the next card is ready for consideration and so on until all the cards for the day are checked. Cards showing short are then held out and placed on the Chief Engineer's desk from which the necessary data for the needed supplies is obtained and at which time he enters the date and quantity ordered in the "Order" column. A good procedure to follow requires that the storeroom attendant place the cards showing deficiencies in supplies on the Engineer's desk each afternoon which will enable him to make out orders the following morning at his leisure, after which the cards are again ready to be returned to the file. A paper clip may be used to indicate the progress through the file, same to be placed on the numeral marker corresponding to the group checked that day.

The above routine is, as stated, a daily task, but after once started, requires but a few minutes and in small plants does not interfere greatly with the duties of any one employee.

When a shipment is received the attendant checks the supplies and by means of the subject markers withdraws the card, or cards, covering the particular item and makes entry as to date and quantity received under "Received," this operation being performed as a part of the daily routine as outlined above.

Inasmuch as nothing has been said regarding the withdrawal of supplies from the storeroom (or cabinets) it is assumed that with the exception in the case of large plants in which an employee may be specifically charged with this duty, no special precautions are taken in this respect. Those who need supplies merely take them as needed but when such items as fittings are reclaimed, they are properly placed by the attendant alone, inasmuch as there is much likelihood of their being put in the wrong compartment by the various individuals.

The advantages of such a system are readily discernible. Sufficient stock is continually carried for normal maintenance and repair purposes and no job need ever be held up for lack of these supplies. Replacements and additions to stock follow a regular schedule thereby eliminating sudden expenditures which are ordinarily the case. Data from which estimates and costs covering certain equipment maintenance can easily be obtained, and theft of supplies also are readily brought to light under the system.

System thus takes the place of haphazard methods and conditions and establishes order with the minimum of both labor and expense.

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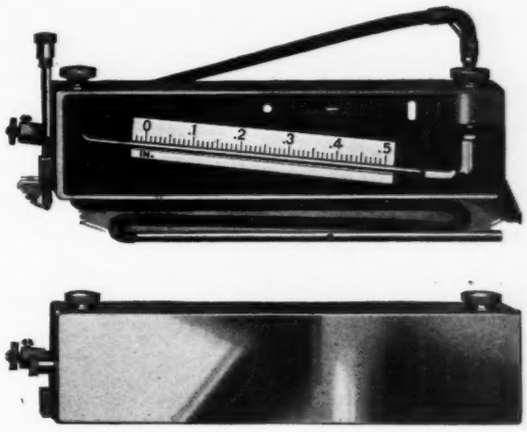

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